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Papers

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MEDIA CHARACTERISTICS IN WATER FILTRATION

Gaurchandra Ghosh[1]
(Proc. Paper 1533)

A fundamental study has been made on the effect of media characteristics in water filtration. Data are presented which show that the current ideas regarding removal of turbidity in the top layers of the filter and turbidity penetration are misconceptions.

INTRODUCTION

The actual mechanism of filtration through a rapid sand filter has not been fully explored, studies in this respect being practically limited to flow of clear water through granular media. There are formulae for predicting the loss of head across a bed of filtering media when clear water is passed through it, but in the case of flow of turbid water it is not known how the loss of head varies and the turbidity is removed at different depths and at different times under different conditions of flow. In actual practice we are concerned not with the flow of clear water, but of turbid water. The present investigations were designed with a view to studying the effects of the physical characteristics of the media when applied to filtration of turbid water, with particular reference to loss of head and removal of turbidity at different depths under different conditions of flow, using media of different size, and without the use of any chemical coagulant or formation of a biological layer which mask the physical characteristics. With a view to studying how sand as a filtering medium differed from a truly spherical porous medium, experiments were first carried out with glass spheres of different size under different conditions of flow; and then all these experiments were repeated with sand of similar uniform size.

The studies relate only to rapid sand filtration, and the range of flow was designed to cover such practice. The author is not aware of any other works where the purely physical aspects of filtration of turbid water have been studied.

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1. Calcutta, India.

Apparatus and Experimental Procedures

The experimental filter of which a sketch is given in Fig. 1, consisted of a 1/4" thick perspex tubing 3 1/2" internal diameter, 5 ft. long. The bottom of the tube was flanged with a 3/8" thick circular perspex plate, and another removable flange fitted with bolts and nuts. The under-drainage system was formed by a circular porous plate, 1/2" thick, supported on an annular hollow perspex cylinder with perforated holes on the sides for easy passage of water, and fixed to the bottom removable flange. A porous plate was considered better than a supporting layer of gravel, as in the latter case it is difficult to maintain a well defined horizontal surface for the bottom of the media. The depth of filtering media used was 30 inches, and there was a constant head of 27" of water over the top surface of the filter-bed. Liquid filtered downwards under a constant head and the excess liquid which over-flowed along the top edge of the filter was collected in an outside annular space and fed back by gravity to the supply tank. The supply inlet to the filter was placed six inches below the top over-flow level.

Connections to a manometer for noting loss of head were made from a point a few inches above the top surface of the media and then from 1/2" below the top surface, followed by intervals of 1", 1 1/2", and then 3" onwards. Sampling points were located exactly opposite these points. One inch pieces of 3/8" diameter solid perspex rods with 40/1000" holes drilled through them were welded on to the body of the filter through 3/8" diameter holes drilled on the sides of the filter at the required points. Connections to glass manometer tubes fixed on an adjacent wooden board, were made by short pieces of rubber tubing. Through the 40/1000" holes of the sampling points were fixed stainless steel tubes which went right to the centre of the filter and projected 3/4" beyond the perspex rods on the outer side. The sampling points had their inside ends blocked and fine horizontal slits were cut on their under sides near the ends. The slits which were cut on a grinding wheel allowed sufficient effluent to enter the tubes, but prevented the entry of fine filtering media. A removable solid stainless steel rod was kept inserted through the stainless steel tube and was removed only at the time of taking samples. Small pieces of rubber corks were used to prevent leakage at the outside ends of the tubes. At the time of drawing samples great care was taken to ensure a slow rate of draw off so that the particles depositing inside the bed were least disturbed. The draw-off could be throttled down and adjusted by inserting a solid steel rod to the outside end of the sampling tube.

The rate of flow through the filter was measured by passing the discharge through a 'Rotameter' which was found suitable for measurements of flow up to a rate of 2 g.p.m. per sq. ft. of filter area. For higher rates of flow the discharge was bye-passed through a venturimeter which was connected to a manometer placed in an inclined plane so as to make it more sensitive. The rotameter and the venturimeter were calibrated from time to time by actually measuring the quantity of flow for different scale readings.

The filter could be back-washed by reversed flow, using tap water under pressure.

Turbid water was prepared by mixing Fuller's earth in tap water. Turbid water was kept constantly agitated by a motor driven stirrer inside the supply tank, from where it was pumped to the top of the filter. The same batch of Fuller's earth was used throughout the experiments and consisted of the following sieve size.

	Retained on 100 mesh (152 Mcs) -	Nil.
Passing	100 mesh (152 Mcs), retained on 120 (124 Mcs) -	0.05 %
"	120 mesh (124 Mcs), " " 150 (104 mcs) -	0.05 %
"	150 mesh (104 mcs), " " 170 (89 mcs) -	4.40 %
"	170 mesh (89 mcs), " " 200 (76 mcs) -	2.56 %
"	200 mesh (76 mcs), " " -	92.89 %

About 93% of the material was finer than 200 mesh. From microscopic measurements of this finer material (passing 200 mesh) the mean size of the particles was found to be 20 microns. Fuller's earth used in the experiments is of comparable size to suspended matter found in raw water in water-works practice.

Experimental Results

Physical Characteristics of the Media Used

TABLE I

Material.	Mean Dia. (Cm)	Mean Sp. gravity.	Porosity.
Glass Ballotini.			
No. 5	0.077	2.90	0.397
No. 6	0.065	"	0.402
No. 8	0.046	"	0.414
Leighton Buzzard Sand			
18-22 mesh.	0.077	2.602	0.37
22-25 "	0.065	"	0.39
30-36 "	0.046	"	0.40

The filtering media were sieved through the relevant adjacent sizes of sieves placed in a motor driven shaker, and the mean diameter taken as the geometric mean of the two sieve sizes (material passing through the higher sieve size and retained on the lower). Specific gravity was measured by the usual standard method, using specific gravity bottles. Porosity was calculated from the dry weight of material used, the volume occupied in the filter, and specific gravity. Theoretically, for the same type of packing, the porosity should be independent of the diameter.(1) But in an actual random packing the porosity increases with the decreasing diameter of particles. This has been found to be the case for both glass ballotini and sand used in the experiments.

Settling Velocities

Settling velocities of the particles of media in water were determined by taking the average of 100 experiments for each sample. To account for differences in density the settling velocities for sand were converted to equivalent settling velocities compared to glass ballotini.

The experimental values of settling velocities have been compared with the values calculated from Allen's modified formula. According to the recommendations of a Committee of the American water-works Association,(2) the settling velocities of particles of diameter > 0.01 but < 0.1 cm, and Reynold's numbers between 1 to 10^3, to which category the present experiments belong, are given by Allen's modified formula—

$$v = 0.20\left[\left(\frac{\rho_s - \rho}{\rho}\right) g\right]^{0.72}\left[\frac{d^{1.18}}{(M/\rho)^{0.45}}\right] \text{ where,}$$

v = settling velocity in cm sec,
g = acceleration due to gravity (cm/sec/sec).
ρ = density of liquid,
ρ_s = density of particles in gms/cm^3
M = viscosity in poise.

The theoretical settling velocities calculated by the above formula have been tabulated in Table II, and are found to be some-what higher than the experimental values. The settling velocities in the range of the experiments, vary as the 1.18 power of the diameters of the particles. From this relation the equivalent diameters for sand particles have been calculated on the basis of their equivalent settling velocities. Glass ballotini being practically true spheres, their sieve diameters and the corresponding settling velocities have been taken as the standards for comparison. The equivalent diameter (based on settling velocity) for sand is found to be less than that of glass ballotini of corresponding sieve size.

TABLE II

Material.	Settling velocity (cm/sec) Calculated from Allen's modified law.	Experimental.	Equivalent Settling velocity.	Equivalent. Dia. (Cm).
Ballotini 5	16.90	13.16	13.16	0.077
-do- 6	13.80	11.00	11.00	0.065
-do- 8	9.15	7.58	7.58	0.046
Sand 18-22.	14.80	10.20	11.10	0.067
Sand 22-25	10.38	8.70	9.49	0.057
Sand 30-36	8.07	6.37	6.98	0.039

Specific Surface per Unit Volume

$$\text{Specific surface of a particle} = \frac{\text{Total area of particle.}}{\text{Total volume of particle.}}$$

$$\text{For a sphere the specific surface 'S'} = \frac{\eta d^2}{\frac{\eta d^3}{6}} = \frac{6}{d}$$

Glass ballotini used in the experiments are practically true spheres. Values of their theoretical specific surface are tabulated in Table III. For experimentally determining the specific surface per unit volume in units of sq.cm/cm^3, the average loss of head over the length of the clean filter was noted, when clean water was passed through it at known approach velocity, and known temperature and hence viscosity, the porosity being already known. By applying these data in the Kozeny equation, and taking the Kozeny constant as 5.0, the specific surface was calculated. Results have been tabulated in Table III.

The Kozeny equation on which calculations have been based, was found by Loudon(3) to agree with his experimental results better than other published

formulae; and as it is seen from Table III, that there is very little difference between the theoretical and experimental values of specific surface for spherical glass ballotini, the technique of measurements adopted in these experiments can be taken as fairly reliable.

TABLE III

Material.	Mean dia. (Cm).	Specific surface - Theoretical.	Sq.Cm/Cm^3 Experimental.
Ballotini No. 5	0.077	78.0	74.2
-do- No. 6	0.065	92.4	97.6
-do- No. 8	0.046	130.4	129.0
Sand 18-22	0.077	-	62.3
Sand 22-25	0.065	-	74.8
Sand 30-36	0.046	-	116.0

From the experimental results it is seen that the specific surface for sand is less than the specific surface for the same sieve size of glass ballotini. The glass ballotini is spherical, but the sand is angular. For the same sieve diameter, the surface of a sphere should be theoretically less than that of angular sand. From the experiments on settling velocities, the equivalent diameters of sand are found to be less than those of glass ballotini of the corresponding sieve size. The diameter being less, the specific surface per unit volume for sand should be greater than that for corresponding glass ballotini. But from the actual loss of head measurements, the reverse is found to be the case. Sand offers less resistance to the flow of water than spherical glass ballotini of corresponding sieve size. The explanation is that in the case of angular sand there are more area contacts between the particles than point contacts, when compared to spherical glass ballotini. Greater area contacts should lead to denser packing, i.e., lower porosity. This has been found to be the case. For the same sieve size, sand is found to be less porous than corresponding ballotini. The specific surface as measured by the tests for loss of head should therefore be regarded as the 'Effective Specific surface per Unit Volume.' That the sand is more angular than glass ballotini has also been confirmed from the tests for settling velocities in water.

A. Experiments with Clear Water Through Clean Beds

For all the media used, the loss of head with clear water for different velocities of flow at different depths of the filter have been recorded and plotted with depth represented on the 'X' axis, and loss of head on the 'Y' axis. (Figs. 2, 3, 4)

Loss of Head at Different Depths

When a clear fluid flows through porous media of uniformly sized particles, the loss of head, as observed by many investigators, is proportional to the depth of the bed. Suggestions have however been made that certain end effects exist arising from energy losses due to sudden contractions and expansions of the fluid at entrance to and exit from the bed respectively, but no investigator

has so far detected any such effect, and there is a general agreement about the linear relationship between loss of head and depth of bed. It is therefore interesting to note that in all the experiments under review, and under all conditions of flow, the graphs representing loss of head against depth are not straight lines but smooth curves. These curves can be represented by equations of the form $Y = ax^b$; where Y represents the loss of head at any depth 'x;' 'a' and 'b' are constants. The values of the constants can be determined by replotting the graphs on logarithmic scales and drawing straight lines of best fit. The value of 'b' which should have been unity under ideal conditions, was found to vary from 0.75 to 0.92 depending on the type of material, but was independent of the velocity of flow.

The constant 'b' may be termed a depth factor 'd_f' and should be introduced into the general form of equation for flow through porous media. As this is a new and original finding, not obtained by any other investigator before, its validity has been discussed in detail in a paper which is being published separately. Assuming that there is no depth factor, and that loss of head is strictly proportional to the depth, then the type of results obtained might be possible under any of the following conditions.

1. Non-uniformity of the particles.
2. Variations in the packing of the bed.
3. Liberation of dissolved gases from the liquid as it moves down the pressure gradient.
4. Electro-kinetic effects.

All these points have been discussed in detail in the paper under reference, and it has been shown that they do not explain the cause of the observed variations. It has been claimed by the author that the end effects whose existence had been suggested by many investigators, have been experimentally discovered. Instead of restricting the phenomena to end effects, the author prefers to represent them by the term 'Depth Factor' and symbolically by d_f, so as to include all possible causes which may contribute to this effect.

Relation Between Loss of Head and Velocity of Flow

Loss of head across a bed of clean filtering media, is proportional to the velocity of flow. To account for the changes in temperature, hence viscosity the values of $\frac{\Delta P}{M}$ (loss of head divided by viscosity) which is theoretically proportional to the velocity of flow, were plotted against velocity, and the points were found to lie in straight lines, confirming that the loss of head due to flow of clear water across a clean bed of filtering media is proportional to the velocity of flow.

Effect of Packing

The packing of a bed has a considerable effect on the loss of head. Effects of slight changes in the porosity of the bed were studied by expanding the bed to 1/2" above the normal level, and also compacting the bed to 1/2" below the normal level. In a few cases the bed was also expanded to 1" above the normal level, and compacted to 1" below the normal level. The fractional voidages for these conditions were calculated. The loss of head across the bed between the points 3 (1 1/2" below the normal top surface) and 12 (27" below the normal top surface) for different conditions of flow, have been plotted

against fractional voidage 'f' (Fig. 5). From the graphs it is noted that the loss of head is not a linear/function of the voidage, and further the following points of interest are also noted.

1. For the same porosity (say 39% or 40%), the loss of head for sand of finer grains is much higher compared to that for coarser grains. Loss of head for sand 30-36 mesh (sieve diameter 0.046 cm) is about 2 1/2 times that for sand 22-25 mesh (sieve diameter 0.065 cm), even when the porosity is the same (39%).

2. The characteristic shapes of curves for sand when compared with those for the corresponding glass ballotini, appear to be different. The curves are concave upwards in the case of sand, but concave downwards in the case of glass ballotini. This leads to the following conclusion. [If the loss of head for sand and corresponding sieve size of glass ballotini for the same condition of flow is assumed to be the same (under some conditions of voidage) to start with, and then the voidage of the two beds are gradually decreased, the increase in loss of head for the two media would proceed under two different rates (concave upward curve for sand, and concave downward for ballotini), so that up to a certain point the loss of head for glass ballotini will be higher than that for the corresponding sand. At a certain point (where the two curves meet) the loss of head for both would again be the same. Beyond this point the loss of head for sand will be correspondingly higher than glass ballotini. This purely hypothetical reasoning has to a certain extent been tested in the case of experiments with turbid water described later. When turbid water is filtered through a medium, the particles deposit inside the bed and the voidage gradually decreases. Beyond a certain stage, it is therefore reasonable to expect that the loss of head for sand should be higher than that for the corresponding glass ballotini. This has actually been found to be the case for sand of 30-36 mesh compared to glass ballotini No. 8 as described later. This subject is evidently a new line of further study and research.

Wall Effect

The diameter of the container (D) was 3 1/2" or 8.89 cm, and the maximum diameter (d) of the media used was 0.077 cm, so that the ratio D/d was over 115. As this ratio is much more than 50, the wall effect has been neglected.(4)

Permeability

By applying Darcy's law, the average permeability of the whole bed was determined experimentally by noting the pressure gradient for different conditions of flow.

$$q = Aki. \text{ or } k = \frac{q}{A\,i} = \frac{q}{A}\frac{\ell}{h} \text{ where, } k = \text{permeability;}$$

q is the volume of water flowing through an area A; h is the loss of head in the length 'ℓ' of the bed.

Permeability has been expressed in centimeters per second per unit hydraulic gradient which represents a loss of head of one centimeter of water in a length of one centimeter. To allow for a comparison of the results under uniform conditions of temperature, the values of k have been converted to permeability at standard temperature of 10:C, by using the appropriate value of viscosity of water. The results for different media and rates of flow of

clear water have been tabulated in Table IV. It is observed that the value of permeability of a medium of particular size is practically constant, and is independent of the velocity of flow. For the same size range, the permeability of sand is higher than the corresponding values for glass ballotini. Sand offers less resistance to the flow of water than glass ballotini.

TABLE IV.

Material.	Rate of flow. (g.p.m.)	Permeability at 10:C. $k10 \times 10^{-1}$
Ballotini No. 5	1.0	4.74
"	1.5	4.53
"	2.0	4.56
"	2.5	4.69
"	3.0	4.63
	Mean	4.63
Ballotini No. 6	1.0	3.58
"	1.5	3.42
"	2.0	3.43
"	2.5	3.58
"	3.0	3.62
	Mean	3.52
Ballotini No. 8.	1.0	1.85
"	1.5	1.77
"	2.0	1.80
"	2.5	1.80
"	3.0	1.805
	Mean . . .	1.805
Sand 18-22	1.0	4.97
"	1.5	4.95
"	2.0	4.95
"	2.5	5.04
"	3.0	5.07
	Mean . . .	5.00
Sand 22-25.	1.0	4.06
"	1.5	4.05
"	2.0	3.97
"	2.5	4.08
"	3.0	4.51
	Mean . . .	4.33
Sand 30-36	1.0	1.98
"	1.5	1.92
"	2.0	1.93
"	2.5	1.98
"	3.0	1.96
	Mean . . .	1.954

Comparison of Results with Hazen's Formula for Permeability

Although such factors as porosity of bed, the shape and size distribution of particles, have been neglected in Hazen's[5] empirical formula for permeability, it is never-the-less popular amongst sanitary engineers, and is certainly useful for determining a rough approximate value of permeability. Hence permeabilities for different media have been calculated by taking a commonly adopted value of 100 for the constant 'C' in Hazen's formula. The values of 'C' corresponding to the experimental values of k have also been calculated. The results are tabulated in Table V.

It is seen that Hazen's formula with 'C' as 100 gave the best results only in the case of sand 22-25 mesh (mean dia. 0.065 cm) which had a porosity of 40%. In other cases Hazen's formula gave higher values of k ranging from 8 to 28%.

TABLE V.

Material.		Experimental k.	Hazen's k (C = 100)	% Variation	Hazen's 'C' for experimental k.
Glass Ballotini	No. 5	.463	.593	+ 28.1	78.3
-do-	No. 6	.352	.423	+ 20	83.4
-do-	No. 8	.181	.212	+ 17.5	85.5
Sand 18-22 Mesh.		.500	.593	+ 18.6	84.5
" 22-25 "		.433	.423	- 2.6	102.2
" 30-36 "		.195	.212	+ 8.3	92.5

B. Results of Experiments with Turbid Water

A large number of the experiments with turbid water were repeated; and the results, after corrections for temperature, hence viscosity, were found to be fairly consistent.

Resistance at Different Depths

Graphs were plotted showing the loss of head at different depths at different intervals of time, for different conditions of flow, and concentrations of turbidity.

These graphs were clearly of the same general form as in the case of flow of clear water under similar conditions. The slopes of these curves become steeper as the time interval increases. The curves correspond to the same general form of equation, $y = a x^{d_f}$, where y represents the loss of head at any depth x, and 'a' and 'd_f' are constants. Evaluation of the constants show that to start with, the constant 'd_f' (depth factor) which represents the slope of the curve, is the same for all velocities, as was found to be the case with clear water. As time proceeds, the curves become steeper, but the degree of steepness is greater with higher velocities. After an interval of time 't' the value of the constant d_f is not the same for all velocities, but is lower for higher velocities, i.e., for higher velocities the slopes are steeper.

Change of Voidage within the Bed

With clear water and a clean filter, let the loss of head between any two points of the bed, distance 'ℓ' be h, and M the viscosity of water: then as per Kozeny equation,

$$u = \frac{1}{K} \frac{f^3}{(1 - f)^2} \frac{1}{MS^2} \frac{gh}{\ell} \qquad (1)$$

u = velocity of flow; f = porosity; S = Specific surface.

When filtration is started, let us assume that after an interval of time 't' the loss of head increases to h', and the porosity of the bed changes to f'. The increase in loss of head between any two points is solely due to deposition of particles of turbid matter in that portion of the bed. These particles may contribute to the increased loss of head in the following ways:-

1. By changing the specific surface which offers resistance to the flow of fluids.
2. By changing the porosity of the bed.

The fine particles of Fuller's earth used in the experiments would most probably deposit in the corners and crevices of the interstices. The flow of fluids is not likely to pass through these particles, because if they come into the flow channels they are likely to be carried away. They may not offer any free resistive surface to the flow in the same way as the particles forming the filtering media. They must settle somewhere in a stable condition if they are to escape being carried away by the flow. Hence they are likely to deposit in the sheltered positions in the corners of the interstices and gradually form conglomerates. Thus the free specific surface of each individual particle does not come into play, but it is only the net exposed surface offered by a group of particles. This new surface formed at the corners of the interstices of the media would have almost the same surface area as the free surface of the media, and should not alter the loss of head as such. At least in the initial stages, and as a first approximation, it may be assumed that the effective specific surface of the media remains constant, and that the increase in loss of head is due to changes in the porosity of the bed caused by the deposition of particles. It is then possible to determine the change in voidage between any two cross-sections of the bed by noting the increased loss of head between these two cross-sections. The change in voidage would give a volumetric representation of the amount of material deposited in the bed. Although this will not be strictly so owing to the surface effects of the deposited particles, it should give at least a fair idea of the pattern of deposition over the bed with which the investigations are more concerned. It is assumed that the increase in loss of head is due to deposition of particles which change only the porosity of the bed, but the specific surface of the media remains almost the same. The rate of flow is kept constant, but owing to changes of temperature the viscosity of the fluid may be different from that obtained during the experiments with clear water, and let this now be M'. Then after an interval of time t, we have,

$$u = \frac{1}{k} \frac{f'^3}{(1 - f')^2} \frac{1}{M'S^2} \frac{gh}{\ell} \qquad (II)$$

From (I) and (II), we get:-

$$\frac{(1 - f')^2}{f'^3} = \frac{(1 - f)^2}{f^3 M'} \frac{M h'}{h}$$

The values of the right hand side are known, and hence the value of the left hand side. The value of f' from the calculated value of $\frac{(1 - f')^2}{f'^3}$ can be found out from a standard curve drawn by plotting values of $\frac{(1 - f)^2}{f^3}$ against known values of 'f.'

Changes in voidage have also been calculated by using Rapier & Duffield function relating relative resistance to porosity. From Rose's experimental results, Rapier & Duffield obtained the following function relating relative resistance to porosity $\phi(f) = 1.115 (1 - f)\left\{ (1 - f)^2 + 0.018 \right\} / f^{1.5}$ where $\phi(f)$ is a function relating relative resistance to porosity, equal to unity at f = 40 percent, and f = fractional voidage. Using the same notation as before, after any interval of time, $\phi(f') = \phi(f) \frac{M}{M'} \frac{h'}{h}$: (f and f' being the original and changed voidage respectively). The value of f' from the calculated value of $\phi(f')$ can be read off another standard curve which can be plotted giving values of $\phi(f) = 1.115 (1 - f) \left\{(1 - f)^2 + 0.018\right\} / f^{1.5}$ against known values of f.

In this way porosities of the bed have been calculated for the volumes of media contained between successive points of the bed, and at different intervals of time. The areas contained between the straight line of original voidage and these curves give a volumetric representation of the material that has deposited between any two points of the bed. The graphs are shown in Figs. 6, 7, 8, the dotted lines indicating the results by Rose equation. The Rose equation gives somewhat higher deposits than Kozeny equation, but the difference in voidage by the two equations is not considerable. Although the results obtained by the two equations are different, the general pattern of deposit is however the same in both cases. It is seen that the deposit with sand is considerably greater when compared with that for the corresponding sieve size of glass ballotini. Although sand offers less resistance to the flow of fluids, as shown before, it retains more turbid material than glass ballotini. In the case of finer material, the first half inch of the bed gets considerably more loaded, but in the case of coarse grains, the burden of removal is well distributed throughout the bed, and extends right to the bottom. When a chemical coagulant is added, the tendency for the floc particles is to coalesce the suspended particles together whereby their bulk is increased, and so they are easily caught in the first layer of obstruction, that is the top portion of the filter. With the addition of chemical coagulants the forces of attraction on the particles are much greater than when no chemical coagulant is added. In the absence of any coagulant, the particles are therefore more free to penetrate the bed. It is more or less the physical straining effect that predominates, so that if the interstices are finer, the material caught between them are numerous. However, the phenomenon is not explainable by physical straining alone. It is definitely clear that sand has much greater affinity for

the particles than glass ballotini. This must be due to some surface properties of the material, which represent its power of adsorption.

Permeability of Bed

From the experimental loss of head readings the average permeability of the bed as a whole for different media, concentrations of initial turbidity, and rates of flow, were calculated for varying intervals of time, and for purposes of comparison these values were converted to permeability at a standard temperature of 10° C, by using the appropriate values of viscosity. The results indicated the following:-

For a concentration of 50 p.p.m, the permeability of the bed diminished with time, due to deposition of turbid material within the bed, but the permeability at any particular interval was practically uniform for all velocities. The permeability was thus independent of the velocity of flow.

When the initial turbidity was raised to 100 p.p.m, similar relations existed only in the case of coarser particles. For finer materials like sand 30-36, the permeability at any time was no longer independent of the velocity. For higher velocities the permeability was definitely lower, indicating that with higher velocities the amount of material deposited was proportionately higher. When the initial turbidity was raised to 200 p.p.m, the conditions were more or less the same.

Thus with higher initial turbidity and finer material, the permeability goes down with higher velocities. When the initial turbidity is high, and the media are fine, there is a comparatively higher degree of deposition in the top layers, and with higher velocities these particles are forced downwards, allowing more particles to be deposited in the top layers. The deposition over the bed as a whole is thus proportionately higher for higher velocities, and hence reduced permeability.

Relation Between Loss of Head and Velocity

Plots of $\Delta P/M$ against velocity of flow, indicated the following.

1. The relation between loss of head and velocity is no longer strictly linear, as was the case with clear water; but even then the relation is approximately linear.

2. In the case of clear water, the loss of head was always less in the case of sand than the corresponding glass ballotini, showing that sand offers less resistance to the flow of water.

3. In the case of turbid water, the loss of head with sand of coarser grains is still correspondingly lower, but for finer material the loss of head for sand is higher than the corresponding glass ballotini. The relation between loss of head and porosity bears a different proportionality in the case of sand compared to glass ballotini, and this point has been discussed under the effects of packing on loss of head with clear water. When filtration proceeds, there is a gradual deposition of material within the bed, and hence the voidage of the bed gradually decreases. It is therefore reasonable to expect that under certain conditions when the voidage goes down below a certain limiting value corresponding to the point of intersection of the two types of curves, the loss of head with sand will be higher than the corresponding glass ballotini. This was actually found to be the case.

Loss of Head with Time

Plots of variations in loss of head with time indicated that the time rate of clogging as measured by lost head, was not constant in every case. In the case of sand, and within the time of experiment, the relation was linear, only for coarse grains (18-22 mesh, and 22-25 mesh). For fine grained sand of mesh 30-36, the clogging rate increased considerably with time for all velocities, being proportionately higher for higher velocities. The picture was the same for both low and high initial turbidities.

For glass ballotini, the increase in loss of head with time was more marked, and even for coarse grains like glass ballotini No. 5 and No. 6, the linear relationship did not exist in the case of higher velocities of flow. For fine grained glass ballotini No. 8, the rate of increase with time was more marked with higher initial turbidity.

Penetration of Turbidity

Samples were collected at hourly intervals from all the sampling points (commencing from half an hour after start of filtration), and turbidity was measured by an 'Absorptiometer.' The results of turbidity indicated the following:-

1. Turbidity penetrates the entire depth of media under almost all conditions of flow. Zero turbidity in the effluent was reached only in a few isolated cases, and that also after filtration had proceeded for some time.

2. There is a gradual removal of turbidity throughout the bed at all depths.

3. It had been observed by other workers who used chemical coagulants, that the top portion of the media took the main burden of removal of turbidity, and afterwards, as the upper layers got clogged, the burden of removal was gradually transferred downwards. In the present experiments (in which no chemical coagulant was used) no such phenomenon was observed, and at no time did any particular layer share the main burden of removal of turbidity.

4. The turbidity of the effluent is in general directly proportional to the velocity of flow. Higher the velocity, greater the turbidity of the effluent.

5. The turbidity of the effluent becomes less with time. The material deposited in the upper layers improves the straining action.

6. As far as the turbidity of the final effluent is concerned, there is not much difference in the characteristics of the different grades of sand. Sand of all three grades yielded effluents of similar turbidities for all values of initial turbidities, when the rate of flow was the same. Under suitable conditions it is therefore much more economical to use a coarser material with a higher initial turbidity.

   With glass ballotini, the turbidity of the final effluent is comparatively higher for higher initial turbidity. Size of the media is not of very great importance.

7. The size of the media has very little influence on the final turbidity. In fact, a coarser material may at times yield a clearer effluent. For removal of turbidity, the voidage of the bed appears to be equally important as the specific surface of the material.

Removal of Turbidity

The turbidity of the final effluent gives an approximate measure of the amount of material that has deposited within the bed. The difference between the initial turbidity and the turbidity of the effluent at any time is the amount of turbidity that has been removed by the media. From the hourly readings of turbidity, the average amount of turbidity removed during one hour, and thence the total amount of turbidity removed within a period (5 1/2 hours) have been calculated, and expressed as a percentage of the applied turbidity which has been removed. The results for different media, with different initial turbidity, and varying rates of flow, have been tabulated in Table VI. An attempt was made to correlate these data with the change of voids calculated from loss of head readings, but this was found difficult due to the fact that in one case we are dealing with weights, and in the other case with the effective volume of the deposited particles the degree of compactness of which would influence loss of head. For the same mass, the volume of a loose conglomerate of deposited particles and the resultant loss of head would be different from those of the same compacted mass. The degree of compactness of the deposited particles is a changing function which is difficult to evaluate.

TABLE VI.

Material	Percentage of Turbidity Removed. Initial Turbidity 50 P.P.M.	100 P.P.M.	200 P.P.M.
I G.P.M.			
Ballotini No. 5	75.3	78.5	73.1
-do- No. 6	76.2	94.9	99.2
-do- No. 8	53.0	92.9	-
Sand 18-22	87.0	97.0	87.4
Sand 22-25	83.7	93.4	82.5
Sand 30-36	92.4	92.3	92.0
2 G.P.M.			
Ballotini No. 5	47.3	56.8	70.7
-do- No. 6	57.6	52.7	39.1
-do- No. 8	37.8	50.3	50.4
Sand 18-22.	87.6	65.1	78.0
Sand 22-25.	62.5	75.7	60.2
Sand 30-36	74.3	93.1	57.9
3 G.P.M.			
Ballotini No. 5.	44.4	46.4	32.8
-do- No. 6.	52.6	41.1	50.5
-do- No. 8	34.4	31.4	27.1
Sand 18-22.	61.4	66.2	44.5
Sand 22-25.	51.4	67.0	64.6
Sand 30-36.	74.8	68.8	50.1

CONCLUSIONS

1. Experimental results clearly indicate that in the case of flow of clean water through a clean bed of filtering media of uniform size, the loss of head across the bed is not strictly proportional to the depth of the bed. The rate of head loss at the top is greater than that at the bottom. Owing to end effects and losses due to sudden enlargements and contractions, and also other unknown causes, the rate of head loss varies with the depth. The same effect will presumably occur in full scale sand filters. The exact cause of this variation is evidently a further line of intensive research.

To express this variation, the author has introduced a depth factor 'd_f' which is a constant whose value depends on the characteristics of the media, and usually lies between 0.75 and 0.92, being unity under ideal conditions. For a clean bed the value of d_f is independent of the velocity of flow.

2. The flow of turbid water through a bed of filtering media without the use of any chemical coagulant, is experimentally found to be comparable to flow of clear water through porous media, but there are two additional variables. The additional variables are (1) Depth factor, and (ii) Time effect. The rate of head loss along the bed in such a case varies still more markedly with the depth, and the depth factor 'd_f' is no longer a constant function. To start with, the value of the depth factor d_f is the same as in the case of flow of clean water through a clean porous bed. With time, owing to deposition of turbid matter inside the bed, the characteristics of the bed continue to change, and the value of d_f decreases continuously. Time is an important factor and the characteristics change continuously with time.

3. At the start of filtration the value of d_f is independent of the velocity of flow. But with time the physical characteristics of the bed (for the same conditions of flow) change differently with varying velocities, and hence d_f becomes a function also of velocity.

4. The rate of head loss for different packings (fractional voidage) of sand varies differently from that of glass ballotini of the corresponding sieve size. From the limited experiments it appears that the curve for loss of head against voidage is concave upwards for sand, against concave downwards for glass ballotini. Therefore on theoretical considerations it is reasonable to expect that if at any time the loss of head for the two media (of the same sieve size) be the same, and then the voidage of the beds are gradually decreased, i.e., the beds are compacted, then the loss of head with sand will continue to be less than that of glass ballotini till a certain stage when it will again be the same, and beyond that stage the loss of head for sand will be proportionately higher. Such a picture has been presented in the case of filtration of turbid water, where gradual deposition of material inside the bed may be looked upon as equivalent to decreasing the voidage i.e., compacting the bed. This phenomenon appears to present ample scope for further study and research.

5. Permeability of a particular medium when clean water is used, is independent of the velocity of flow. For the same size range (nominal sieve size), the permeability of sand is higher than the corresponding values for glass ballotini. Sand offers less resistance to the flow of water then glass ballotini of the same sieve size.

6. When turbid water is filtered through a medium, the permeability of the bed diminishes as the time interval increases. For low initial turbidity, the permeability still remains independent of the velocity. But with higher initial turbidity and finer material, the permeability no longer remains proportional to the velocity; the decrease of permeability with time being higher for higher velocities.

7. From a study of the changes in the voidage of bed, the following conclusions are arrived at:

i) Although sand offers less resistance to the flow of fluids, it adsorbs more material in comparison with glass ballotini of the corresponding sieve size.

ii) The usual belief that it is the first few inches of a filter bed which take up the major burden of filtration, is not correct when chemical coagulants are not used. In the case of finer material and high initial turbidity, the first three inches of the bed, and specially the first half inch, do get considerably more loaded than the rest of the bed, but with coarse grains the burden of removal is well distributed throughout the bed, and extends right to the bottom.

8. The time rate of clogging, as measured by the lost head, varies for different media and conditions of flow, and is by no means constant. The rate is constant only in the case of coarse grains and low velocities, and within the length of filter runs used in the experiments; but increases considerably with time in the case of finer grains and higher velocities. The rate is slightly higher for glass ballotini than sand, thus conforming to the general picture for loss of head for the two materials.

9. Turbidity penetrates the entire depth of media under almost all conditions of flow, and there is a gradual reduction in turbidity all along the depth.

10. The final turbidity of the filtrate depends much more on the velocity of flow than on the size of the media. The turbidity is high for higher velocity.

11. Percentage of material deposited inside a bed does not vary considerably with varying initial turbidity. For treating water of high turbidity, it may therefore be more economical to have primary rapid filtration, rather than prior settlement or coagulation.

12. For obtaining a filtrate of low turbidity, the most effective measure appears to be the reduction of the velocity of flow.

13. Sand produces a clearer filtrate than glass ballotini of the corresponding sieve size.

ACKNOWLEDGMENT

The paper has been condensed from the author's Ph.D thesis (1956) of the University of London. The research works were carried out at the Imperial College of Science & Technology, London, under the supervision of Mr. F. E. Bruce, Reader in Public Health Engineering, to whom the author is highly indebted.

BIBLIOGRAPHY

1. Graton L. C. & Fraser H. J. (1935) - Systematic packing of Spheres. Jour. of Geol. Vol. 43.

2. American Waterworks Association (1955) - Proposed Revision of chapter 8 of 'Water quality & Treatment' J.A.W.W.A. Vol. 47. No. 8.

3. Loudon A. G. (1952) - The computation of permeability from Simple Soil Tests. Geotechnique. Vol. 3.

4. Rose H. E. & Rizk A.M.A. (1949) - Proc. Inst. of Mech. Engrs. Vol. 160. P. 493.

5. Hazen Allen (1892) - Some Physical properties of Sands & Gravels. 24th Annual Report, Mass. State Board of Health.

6. Rose H. E. (1950) - Fluid flow through beds of granular material. Inst. of Physics Symposium.

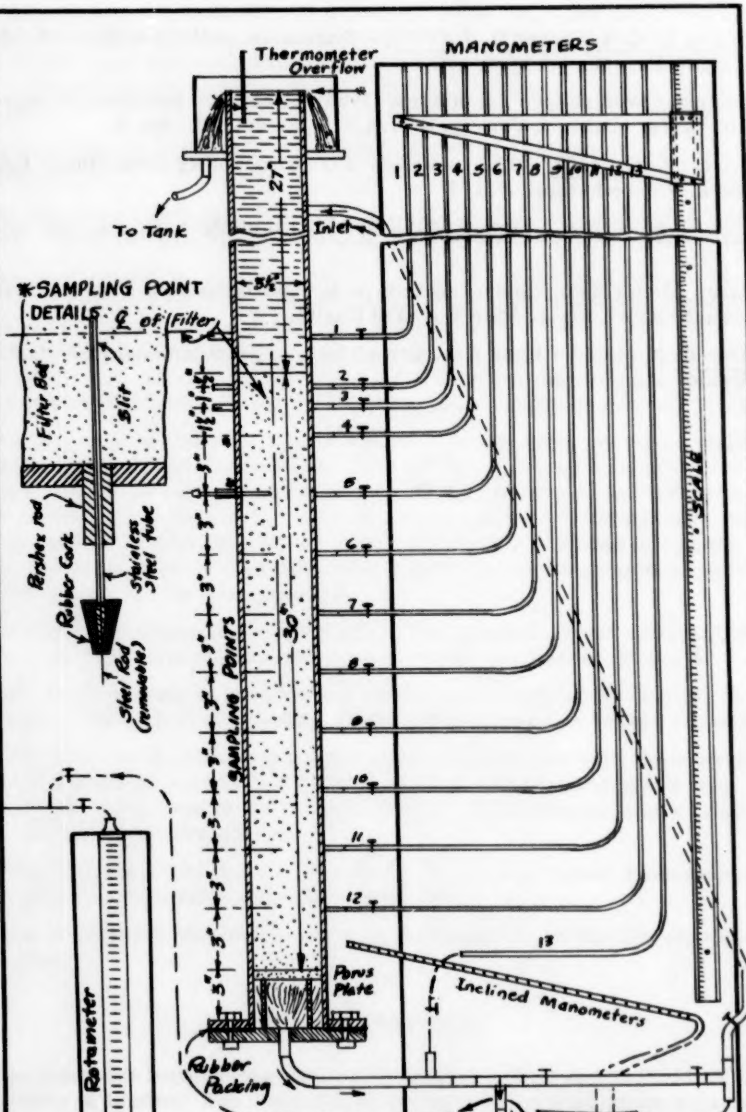

MANOMETERS
Thermometer
Overflow
To Tank
Inlet
27"
3½"
*SAMPLING POINT
DETAILS
℄ of Filter
Filter Bed
Slit
Pershex rod
Rubber Cork
Stainless Steel tube
Steel Rod (removable)
SAMPLING POINTS
30"
SCALE
Porus Plate
Inclined Manometers
Rubber Packing
Rotameter
Venturi Meter
From Pump

Fig. 1.

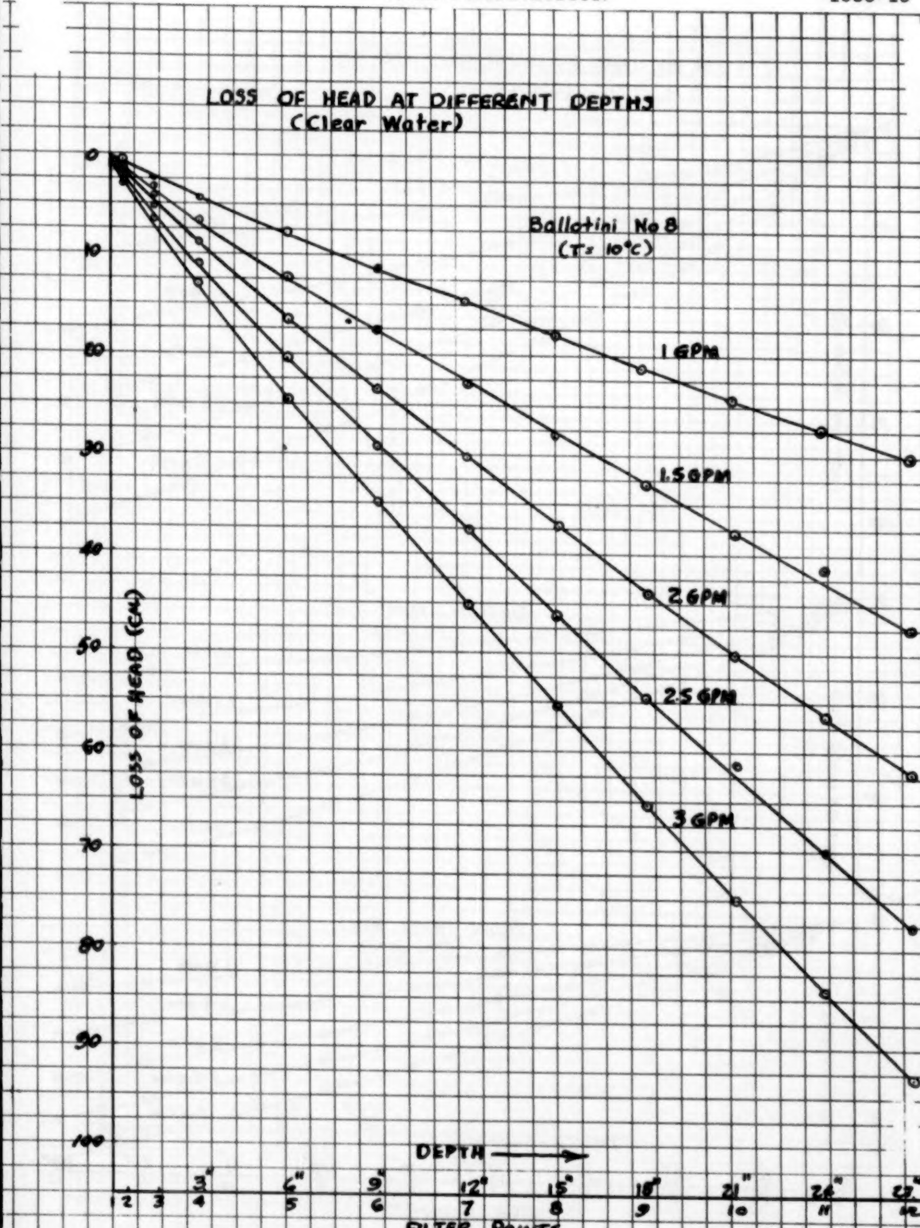

LOSS OF HEAD AT DIFFERENT DEPTHS
(Clear Water)
Ballotini No 8
(T= 10°C)
1 GPM
1.5 GPM
2 GPM
2.5 GPM
3 GPM
LOSS OF HEAD (CM)
0
10
20
30
40
50
60
70
80
90
100
DEPTH
3"
6"
9"
12"
15"
18"
21"
24"
27"
1
2
3
4
5
6
7
8
9
10
11
12
FILTER POINTS

Fig. 2.

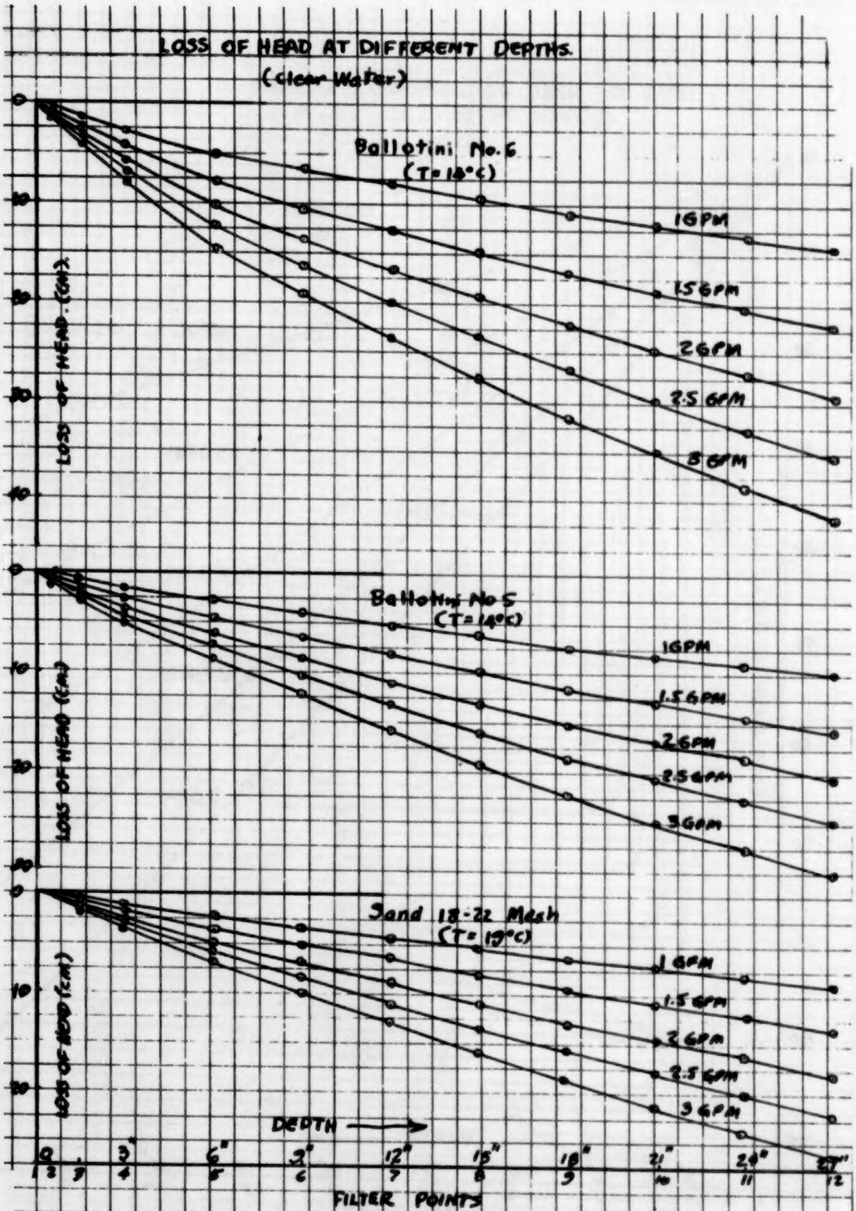

LOSS OF HEAD AT DIFFERENT DEPTHS.
(Clear Water)
Ballotini No. 6
(T=18°C)
1GPM
1.5GPM
2GPM
2.5GPM
3GPM
LOSS OF HEAD (CM)
Ballotini No 5
(T=14°C)
LOSS OF HEAD (CM)
Sand 18-22 Mesh
(T=19°C)
LOSS OF HEAD (CM)
DEPTH
FILTER POINTS

Fig. 3.

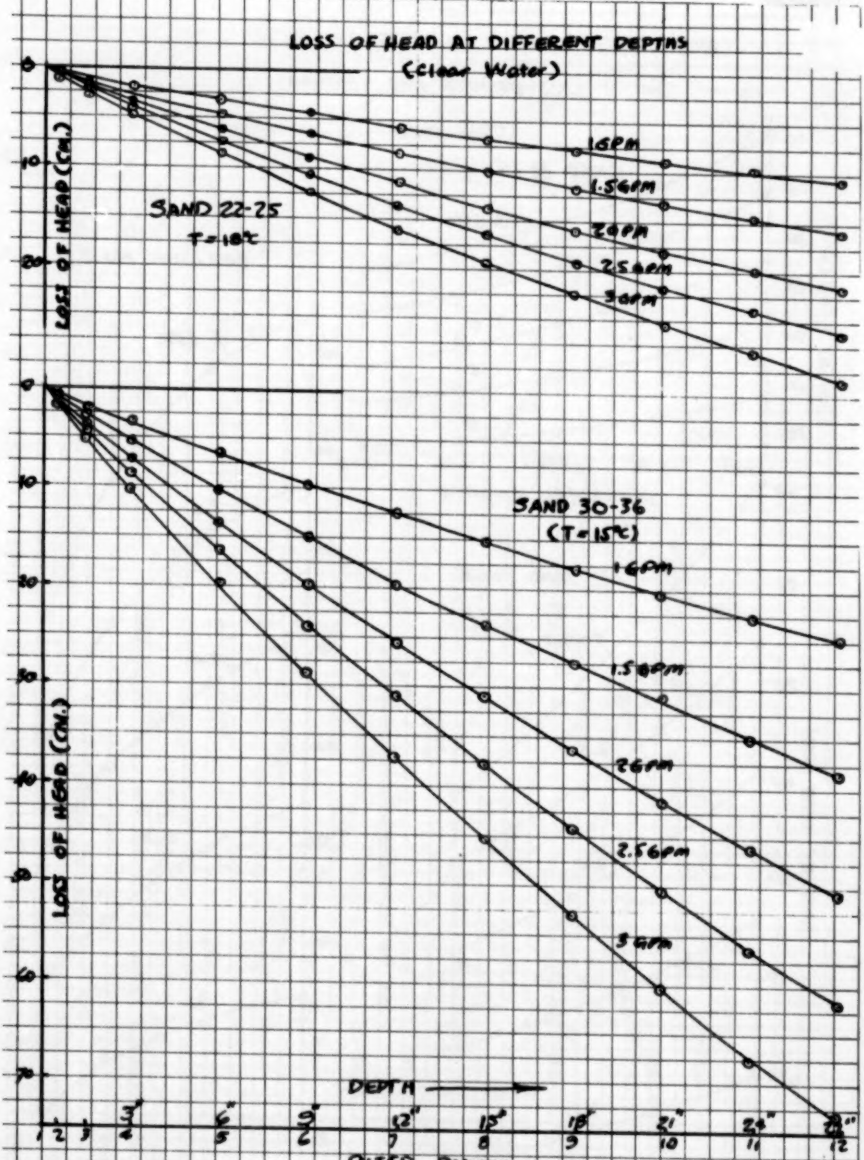
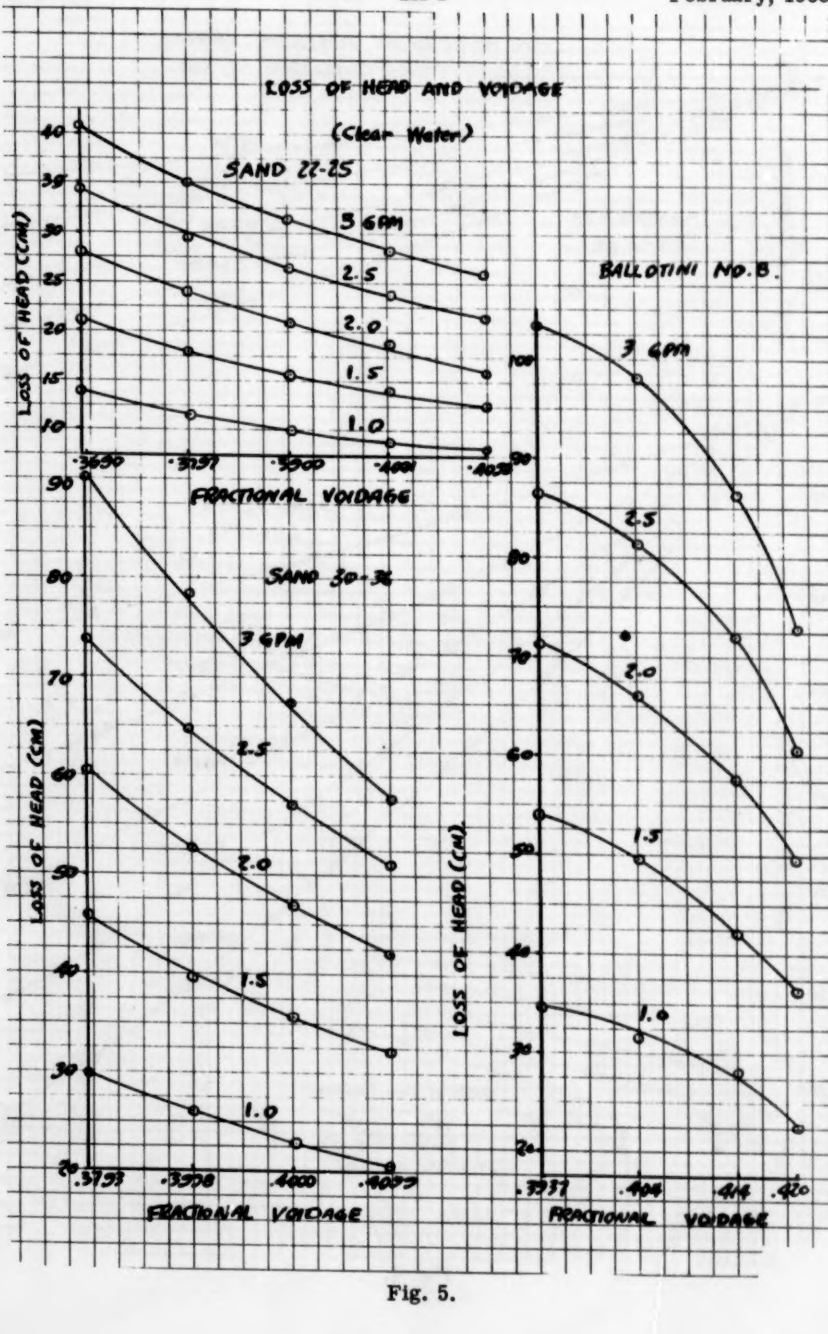

LOSS OF HEAD AT DIFFERENT DEPTHS
(Clear Water)
LOSS OF HEAD (CM.)
SAND 22-25
T=18°C
1GPM
1.5GPM
2GPM
2.5GPM
3GPM
SAND 30-36
(T=15°C)
2.5GPM
3GPM
DEPTH
3"
6"
9"
12"
15"
18"
21"
24"
FILTER POINTS
0
10
20
30
40
50
60
70

Fig. 4.



LOSS OF HEAD AND VOIDAGE
(Clear Water)
SAND 22-25
3 GPM
2.5
2.0
1.5
1.0
LOSS OF HEAD (CM)
FRACTIONAL VOIDAGE
SAND 30-36
3 GPM
2.5
2.0
1.5
1.0
LOSS OF HEAD (CM)
FRACTIONAL VOIDAGE
BALLOTINI NO. B.
3 GPM
2.5
2.0
1.5
1.0
LOSS OF HEAD (CM)
FRACTIONAL VOIDAGE

Fig. 5.

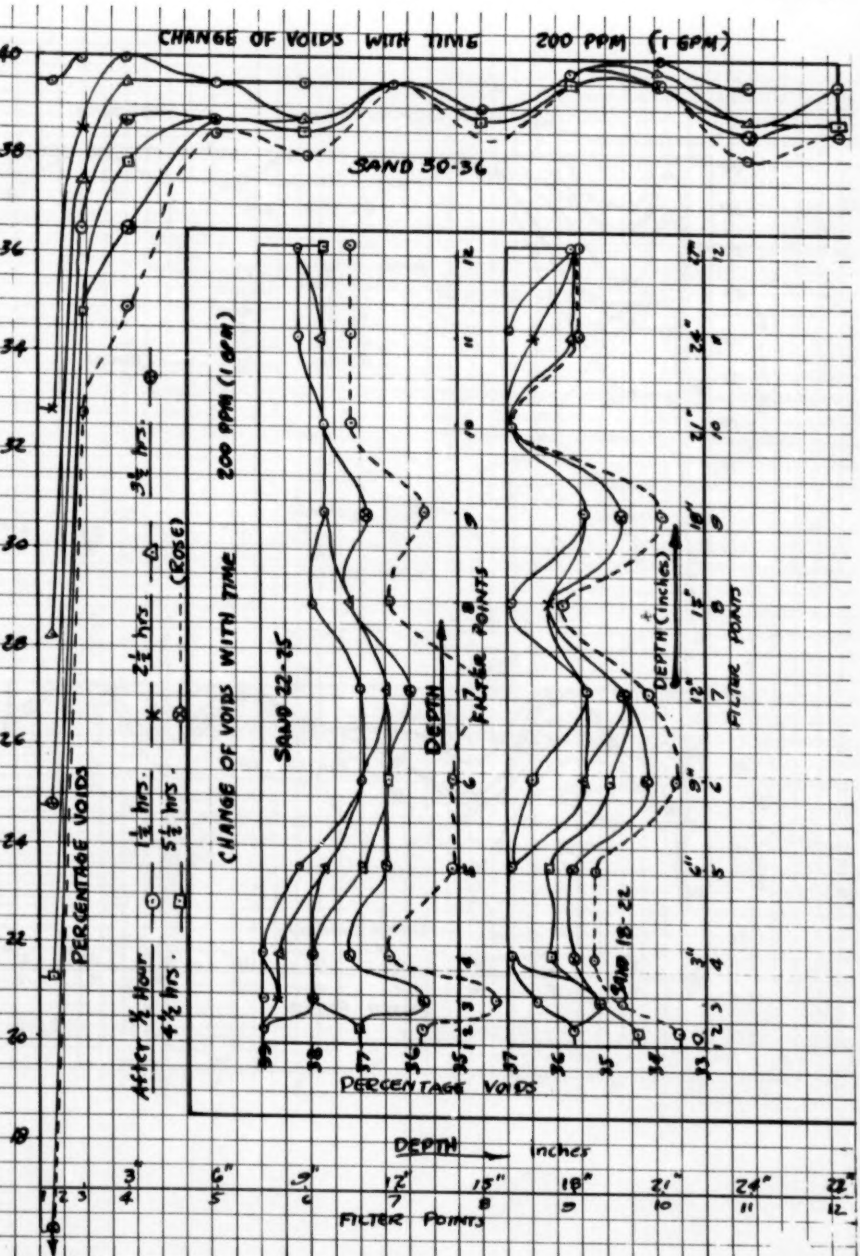
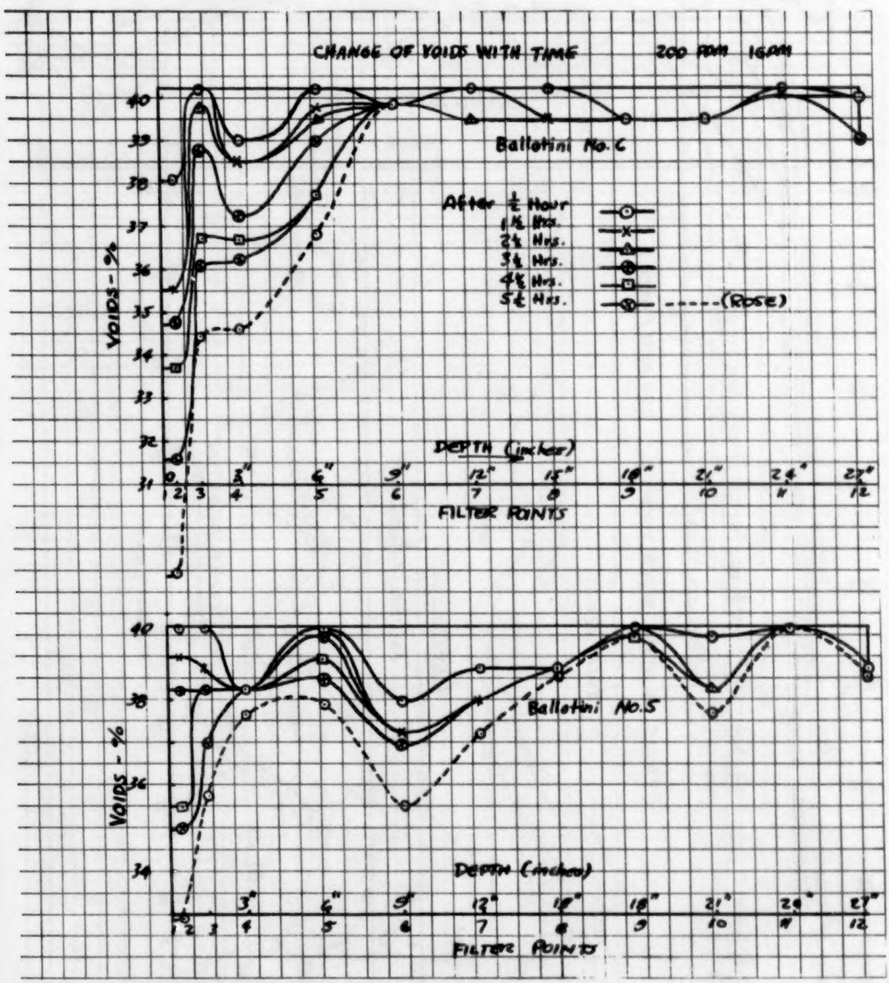

CHANGE OF VOIDS WITH TIME 200 PPM (1 GPM)
SAND 30-36
PERCENTAGE VOIDS
DEPTH inches
FILTER POINTS
After ½ Hour 1½ hrs. 2½ hrs. 3½ hrs.
4½ hrs. 5½ hrs. (ROSE)
CHANGE OF VOIDS WITH TIME 200 PPM (1 GPM)
SAND 22-25
SAND 18-22
DEPTH
DEPTH (inches)
FILTER POINTS
PERCENTAGE VOIDS

Fig. 6.



CHANGE OF VOIDS WITH TIME 200 RPM 16GPM
Ballotini No. 6
After ½ Hour
1½ Hrs.
2½ Hrs.
3½ Hrs.
4½ Hrs.
5½ Hrs.
(ROSE)
VOIDS - %
DEPTH (inches)
FILTER POINTS
Ballotini No. 5

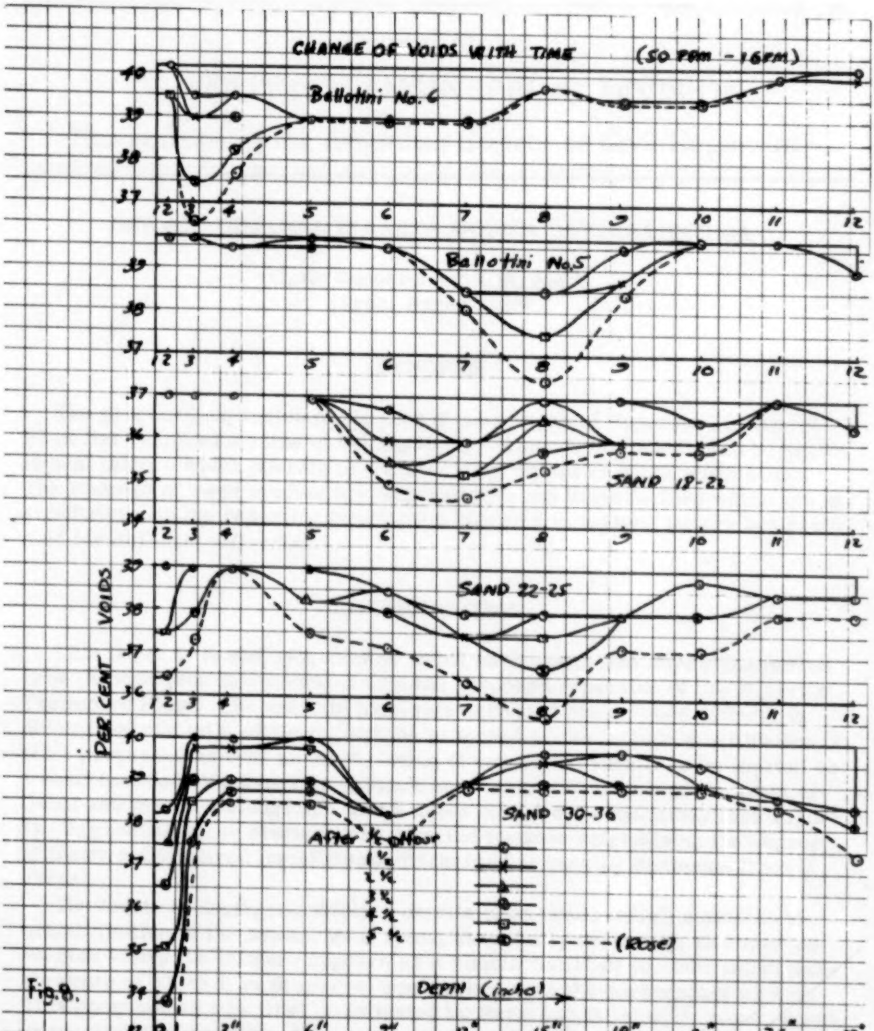

CHANGE OF VOIDS WITH TIME (50 PPM - 1 GPM)
Ballotini No. 6
Ballotini No. 5
SAND 18-22
SAND 22-25
SAND 30-36
PER CENT VOIDS
After ½ Hour
1½
2½
3½
4½
5½
(Rose)
DEPTH (inches)
2" 6" 9" 12" 15" 18" 21" 24" 27"

Fig. 8.

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Proceedings of the American Society of Civil Engineers

SEWAGE DISPOSAL IN SANTA MONICA BAY, CALIFORNIA

C. G. Gunnerson,* A.M. ASCE
(Proc. Paper 1534)

SYNOPSIS

The proposed expansion of the City of Los Angeles' Hyperion Treatment Plant has required studies of the physical, chemical, biological, and bacteriological factors which operate in the receiving waters of Santa Monica Bay. The findings of these studies are summarized, and those factors which are of significance in the reduction of coliform bacteria in surface waters are evaluated for different effluents.

INTRODUCTION

This paper is based upon studies which have been made during the period 1954 through 1956 in connection with the proposed expansion of the Hyperion Treatment Plant. The existing high-rate activated sludge plant effluent is discharged one mile offshore, and the proposed works include modification of plant processes as well as construction of two ocean outfalls to be located on a shelf bounded by submarine canyons and which will discharge the plant effluent and digested sludge at 5 and 7 miles offshore, respectively (see Figure 1). In general, these studies were directed towards determining the degree of treatment required for effluents discharged at varying distances from shore.

The location, depth, and diffuser details of an ocean outfall establish the initial dilution of the sewage as it rises, essentially vertically, to either the surface where the mixture appears as a visible "boil" or to some intermediate depth at which it is in general equilibrium with the surrounding waters. This phenomenon was first investigated by Rawn and Palmer,[1] more recently re-evaluated by Rawn, Bowerman, and Brooks,[2] and has been reviewed by Pearson.[3] The initial diffusion represents the point at which control exercised by engineering works ends. This study is concerned with those factors operating subsequently in the marine environment which may be expected to indicate the degree of treatment required of the plant on shore.

Note: Discussion open until July 1, 1958. A postponement of this closing date can be obtained by writing to the ASCE Manager of Technical Publications. Paper 1534 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. SA 1, February, 1958.

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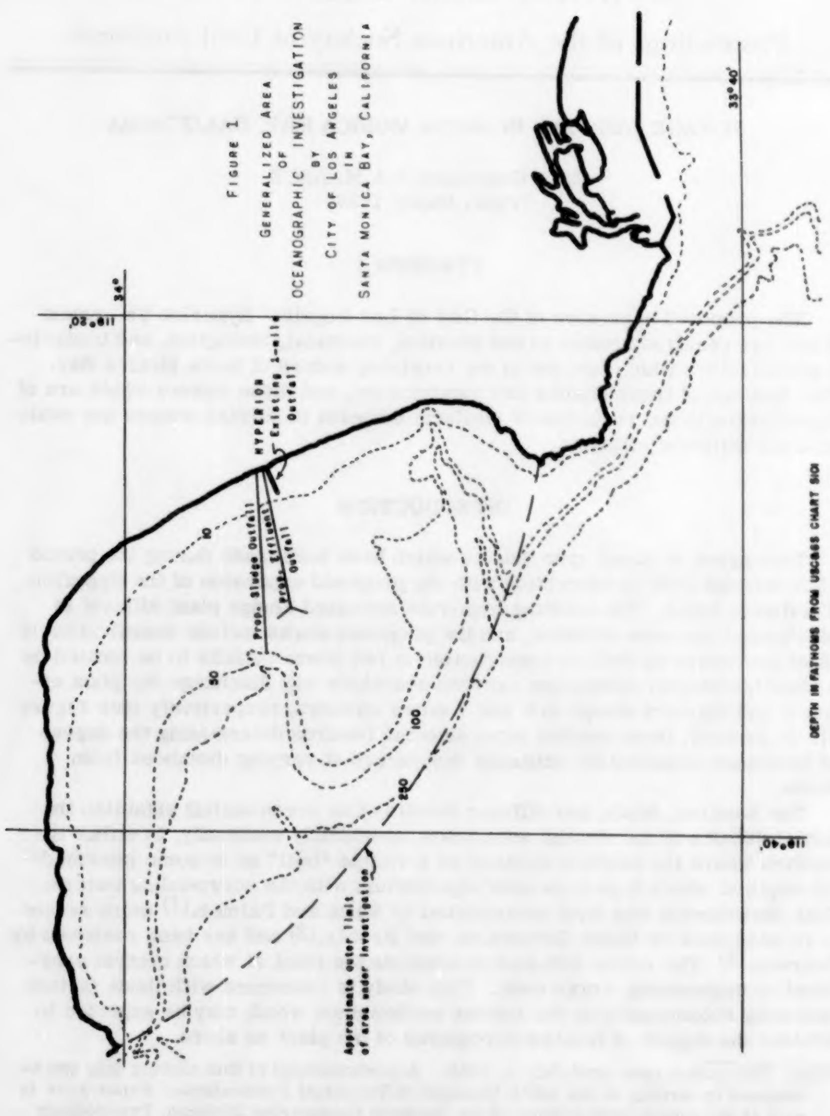


FIGURE 1
GENERALIZED AREA OF OCEANOGRAPHIC INVESTIGATION BY CITY OF LOS ANGELES IN SANTA MONICA BAY, CALIFORNIA

A treatment plant effluent will necessarily undergo various changes in characteristics after discharge into the receiving waters, and this implies consequent changes within the waters themselves. For purposes of discussion, the factors that produce these changes may conveniently be classified as physical, chemical, biological, and bacteriological. It must be recognized, however, that the various factors are inter-related and that, while an arbitrary separation permits a reasonable analysis of their effects, such a separation is, in fact, artificial.

Physical and Chemical Factors

The physical dilution of an effluent discharged into marine waters is ultimately limited by the amount of new water which is being brought into the area. The determination of the circulation pattern and of the variations of the currents which contribute to this pattern is therefore essential. While the available time, equipment, and personnel did not permit a complete study of the currents and circulation of Santa Monica Bay, a reasonably thorough study was possible which, based on data obtained from current meters, drift cards, current crosses at both the surface and at depth, and observations of the areal extent and location of the various water masses, indicated the average currents, variations from the average, and generalized circulation of the waters in the bay.[4,5]

In general, current observations in the upper 10 feet of water indicate that effluent discharged 5 miles offshore and reaching the surface will require about 20 hours to reach the surf zone during those periods when on-shore currents prevail, and that significantly lower current velocities prevail in waters at depth.

The operation of the diffuser system, as indicated by the dilution at the boil, will determine the efficiency with which the effluent will be initially diluted by the waters coming into the area, although, as stated above, discussion of initial dilution is beyond the scope of this paper.

Subsequent dilution of the mixture will occur, and may be tentatively divided into two separate phenomena; turbulent mixing due to density variations in the initial mixture which may continue for some three or four hours downstream from the boil, and lateral mixing due to eddy diffusion which is effective thereafter.

Turbulent mixing is herein assumed to be that which is due to the fact that the initial mixture at the top of the rising column is not completely homogeneous, and that therefore there are significant variations in solids, bacteria, salinity, temperature, density, and other characteristics among successive samples taken from the boil as well as from closely-spaced locations within the sewage field immediately downstream. It follows that a significant amount of energy, represented by variations in density, is available for turbulent mixing, both vertical and horizontal.

Lateral mixing which occurs after the first three or four hours of flow from the boil is evidenced by the progressive widening of the field as it travels with the current. This is assumed to be due to eddy diffusion which has been defined[3] as "the interchange or translation of molecules or suspended colloidal matter by the random velocities or turbulence in turbulent flow." Only the lateral or horizontal eddy diffusion is here considered to be important, since the stable stratification in the upper layers of the ocean

indicates that the vertical eddy diffusion is reduced to a relatively small amount.(6)

While the available time did not permit a completely satisfactory analysis of turbulent and lateral mixing at Hyperion, several observations(7,8) of the operation of the existing outfall are summarized on Figure 2 which shows a typical configuration of the sewage field with a northerly current of about 0.3 knot. The dilution factors in parts new sea water per part of plant discharge or subsequent mixture which is influent to the particular phenomenon are about 20, 4, and 2 for initial dilution, turbulent mixing, and lateral dilution, respectively. The resulting net dilutions in parts sea water per part of plant effluent are about 20:1 for initial dilution, 100:1 after some 4 hours of turbulent mixing, and 300:1 after an additional 20 hours of lateral dilution.

Lateral dilution has also been evaluated by means of dye streams which were released from anchored skiffs located about 5 miles offshore and subsequently observed from both the surface and the air. The results of these studies are summarized on Figure 3. Figure 4 shows, in c.g.s. units, the eddy diffusivity constant as a function of the scale of the phenomena (L) where the scale is taken as the average width of the dye stream. The function $k = 0.01L^{4/3}$ is taken from Pearson(3) for comparison, while the best-fit curve $k = 0.005L^{4/3}$ is based on the observed data. Figure 5 shows the eddy diffusivity constant as a function of time in which the effect of current velocity is indicated. A further discussion of the effect of dilution upon the density of coliform bacteria in ocean waters will be found in a subsequent section of this paper.

The discharge of a plant effluent into sea water has been observed to markedly affect the temperature and salinity, and thus the density, structure of the receiving waters, as well as its general turbidity and appearance. This is most marked near the outfall where a distinct field may be seen. In addition, a fairly well-defined in-shore water mass which has an areal extent of some 20 square miles in Santa Monica Bay may be identified which, in general, has intermediate characteristics between those of the distinct field and of the offshore waters, and which is characteristically outlined by alternating streaks of smooth and rough water, foam lines consisting essentially of marine organisms, and color changes at the surface.

It may be noted that other discharges which contribute to the in-shore water mass include the cooling waters from two nearby steam power plants. Calculations of the heat budget of the Bay have shown(4) that while the contributions of sensible heat from the two major sources, Hyperion effluent and the cooling waters, are about equal, the greater effect of the salinity difference of the fresh water effluent indicates that the in-shore mass is almost entirely due to Hyperion operations.

The chemical changes in the receiving waters near Hyperion include generally a minor reduction in dissolved oxygen and a significant increase in the nutrient elements, nitrogen, and phosphorous, near the outfall.(9) Present analytical techniques are such that changes in concentrations of these elements can be measured with assurance only in the area near the outfall.

Biological Factors

Sewage plant effluents which are of necessity rich in both nutrient elements and food for saprophytes and which are discharged into marine waters may be

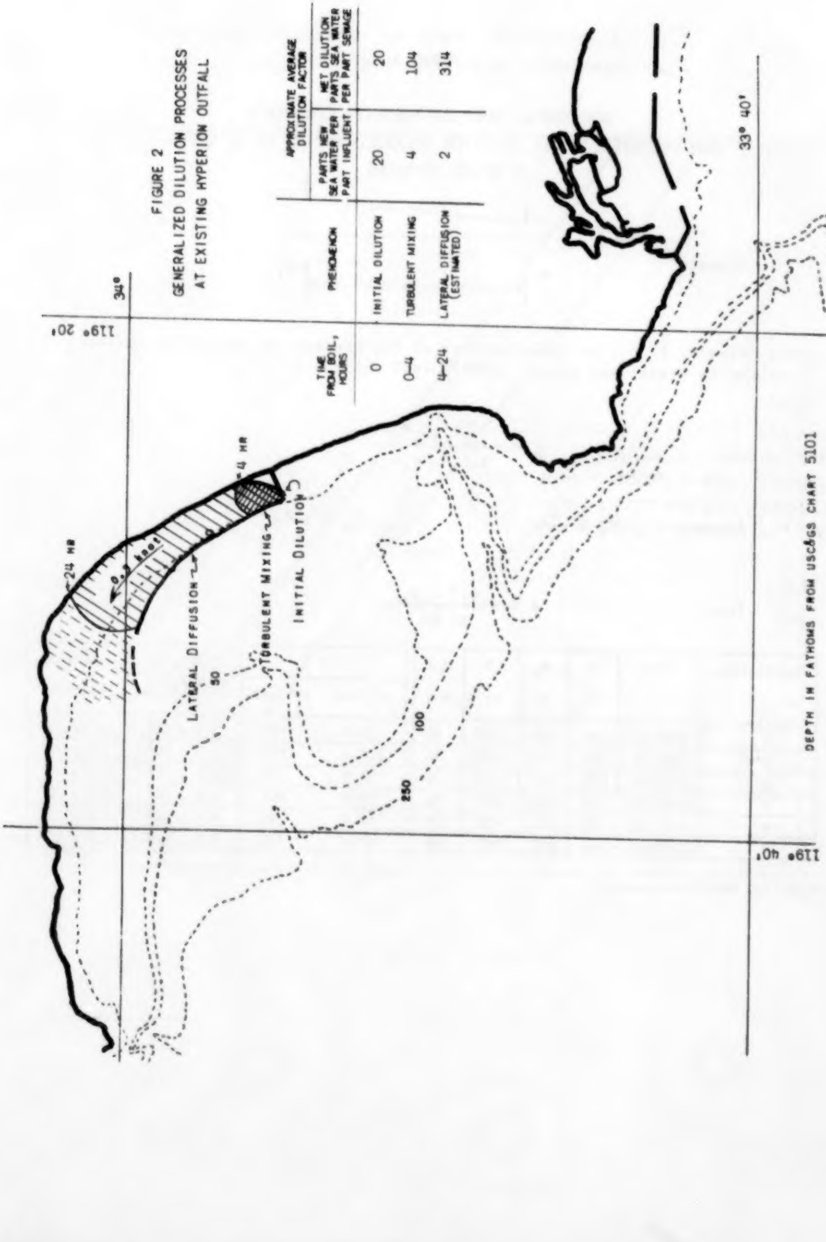
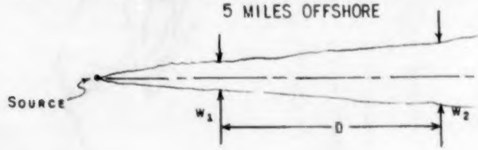


FIGURE 2
GENERALIZED DILUTION PROCESSES AT EXISTING HYPERION OUTFALL

TIME FROM BOIL, HOURS	PHENOMENON	APPROXIMATE AVERAGE DILUTION FACTOR: PARTS NEW SEA WATER PER PART INFLUENT	APPROXIMATE AVERAGE DILUTION FACTOR: NET DILUTION PARTS SEA WATER PER PART SEWAGE
0	INITIAL DILUTION	20	20
0—4	TURBULENT MIXING	4	104
4—24	LATERAL DIFFUSION (ESTIMATED)	2	314

FIGURE 3

HORIZONTAL EDDY DIFFUSIVITY CONSTANTS
FOR FLUORESCEIN DYE SOLUTION RELEASED IN 180 FT OF WATER
5 MILES OFFSHORE



From Pearson, E. A., An Investigation of The Efficacy of Submarine Outfall Disposal of Sewage and Sludge (1956), pp67

$$k = \frac{\sigma_2^2 - \sigma_1^2}{2(t_2 - t_1)}$$

Assume: $\sigma_1 = \frac{w_1}{4}$ $\sigma_2 = \frac{w_2}{4}$

Thus: $k = \frac{w_2^2 - w_1^2}{32\,\Delta T}$

Observation	Date	w_1 FT	w_2 FT	D FT	ΔT MIN	k ft^2/min	k cm^2/sec	Scale, L, $\frac{w_1 + w_2}{2}$, cm	ΔT seconds
1	5/24/55	150	225	1020	28	31.4	487	5.7×10^3	1.7×10^3
2[a]	5/24/55	225	600	2100	90	107.4	1665	1.3×10^4	5.4×10^3
3	12/30/55	60	120	1500	30	11.2	174	2.7×10^3	1.8×10^3
4	12/30/55	67	233	3000	60	25.9	402	4.6×10^3	3.6×10^3
5	12/30/55	150	475	6750	135	47.0	729	9.5×10^3	8.1×10^3
6	12/30/55	150	500	7500	150	47.4	735	9.9×10^3	9.0×10^3

Note: (a) Near Convergence

FIGURE 4

OBSERVED VARIATION IN EDDY DIFFUSIVITY, k, AND SCALE, L, OF DYE DIFFUSION PHENOMENA

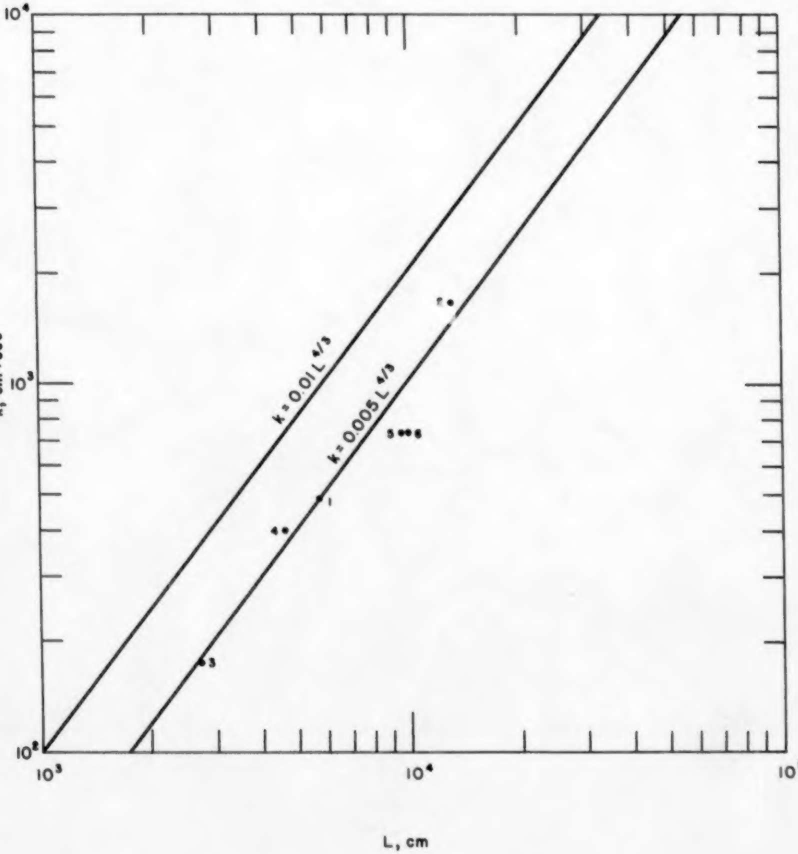
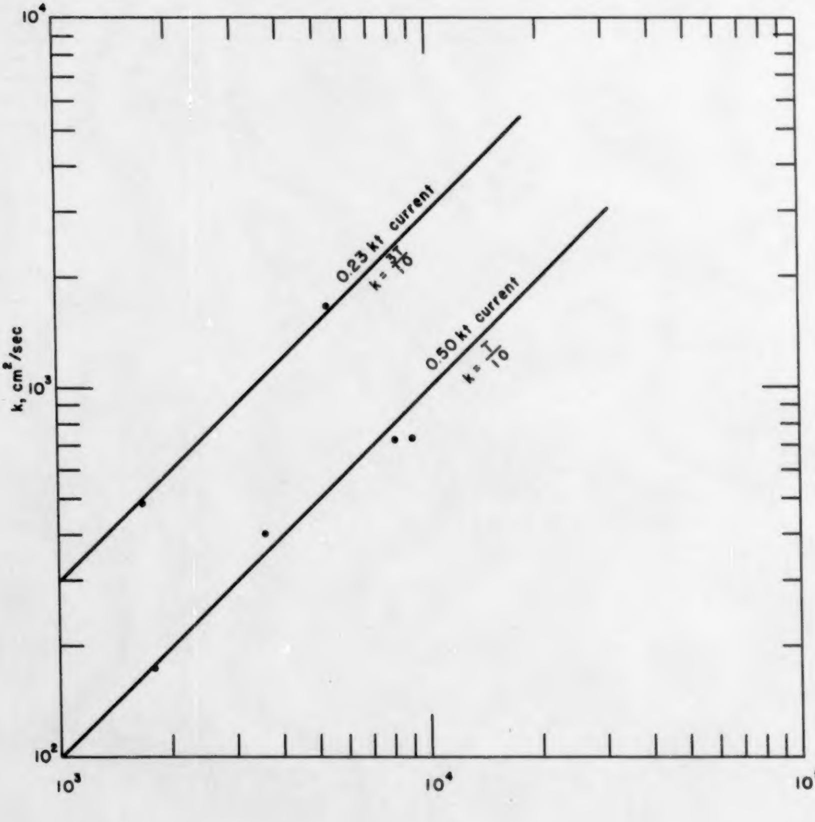


FIGURE 5

OBSERVED VARIATION IN EDDY DIFFUSIVITY, k, AND TIME, T, OF DYE DIFFUSION PHENOMENA



expected to have varying effects upon the plankton (floating or weakly swimming forms, both plant and animal), nekton (swimming animals), and benthos (attached, burrowing, or creeping organisms found on the bottom). General discussions of the role of nutrients in marine life cycles are given by Sverdrup, Johnson, and Fleming[6] and by Harvey.[10]

The discharge of significant quantities of nutrients may reasonably be assumed to result in increased growths of plants (phytoplankton) in the area effected, and possibly an increase in the number of grazing animals (zooplankton) as well. An increase in plankton populations in the vicinity of various ocean outfalls in the Los Angeles area has been noted during the investigations referred to herein,[7,9,11] although there is no evidence that the increased nutrient concentrations will, in themselves, cause the intense blooms which are occasionally noted. In this regard, Stevenson has stated[9] that once a bloom is initiated, ". . . . . the nutrients contributed by the effluent markedly increase the reproductive rate, and thus the numbers of plankton."

The California Department of Fish and Game has made a limited study of bottom fish in Santa Monica Bay which indicate that the Hyperion discharge has had no significant effects upon the fish population.[12] A qualitative confirmation of these results is gained from the observation of sardine and bait boats occasionally operating in the general area of the outfall.

As might be expected, however, the effects of Hyperion sewage upon the benthos is more marked. Hartman[13,14] has discussed these effects, and has, on the basis of the types and numbers of worms, starfish, and crustaceans, defined bottom areas in the vicinity of the existing ocean outfall into various faunal zones which are summarized on Table 1. It should be noted that the relationships shown on the table are generalized from data obtained from locations on the shelf in order to permit an evaluation of pollution, and that variations in individual samples may be expected which are due to the depth, type of sediment, temperature, currents, and biological associations. The effect of the existing discharge upon the benthos is reflected in the numbers of bottom-dwelling fish (flounders and soles) caught per 10-minute drag with an otter trawl by the State Department of Fish and Game.[12] It may be assumed that these fish, having a certain freedom of movement, will be found where their food is most abundant; in this case, over the limited - enriched faunal zone.

Because of the general nature of the bottom and its normally associated organisms, the existing Hyperion discharge has had no noticeable economic effect upon commercial or sport fishing. However, the California Department of Fish and Game has made observations which indicate that abalone have been significantly affected by sewage discharged into their normal habitat.[12] Similar effects upon such other shellfish as oysters and clams have long been noted and reported.[3] Thus, the effects of sewage treatment plant effluents must be evaluated in terms of a particular area of discharge, and can be applied to other areas only with considerable caution.

Bacteriological Factors

Studies of the viability of enteric organisms in sea water have been conducted for many years, and excellent reviews of the literature have recently been reported by Moore,[15] Pearson,[3] Greenberg,[16] Orlob,[17] and Terry.[18] The various studies, which in general seem to have been primarily

TABLE 1

GENERALIZED EFFECT OF EXISTING HYPERION DISCHARGE UPON BENTHOS AND BOTTOM FISH

FAUNAL ZONE	BENTHOS (AFTER HARTMAN[13,14])						AVERAGE NUMBER OF BOTTOM FISH (FLATFISH) FROM TRAWLING[12]
	DISTANCE FROM OUTFALL, MILES	NUMBER OF SPECIES	NUMBER OF INDIVIDUALS (BIOMASS)	BIO-INDEX NO. SPECIES / NO. INDIVIDUALS	NUMBER OF DETRITUS FEEDERS	TYPICAL INDICATOR SPECIES*	
LIMITED POLLUTION (GENERALLY NON-REPRODUCTIVE STAGES)	0 - 1/2	MINIMUM	↓	↓	MAXIMUM	*Capitella capitata* *Diopatra ornata*	12.5
POLLUTION TOLERANT (LIMITED NUMBER OF SPECIES MATURING AND REPRODUCING)	1/2 - 2	↓	INCREASING ↓	DECREASING ↓	↓	*Nereis procera* *Nothria elegans*	16.0
LIMITED ENRICHED	2 - 4	INCREASING ↓	MAXIMUM	MINIMUM	DECREASING ↓	*Amphipholis squamata* *Astropecten californicus*	21.9
UNLIMITED DIMINISHED	4 - 6	↓	↓	↓	↓	*Onuphis nebulosa*	
NORMAL	>6	↓	DECREASING ↓	INCREASING ↓	↓		12.4

NOTE: *—WHILE INDICATOR SPECIES ARE NOT EXCLUSIVELY RESTRICTED TO THE FAUNAL ZONE SHOWN, THEY FORM A SIGNIFICANT PORTION OF THE BOTTOM FORMS PRESENT.

directed towards determining the ultimate survival of bacteria in sea water, have necessarily involved certain artificial conditions which make the results of such studies somewhat difficult to apply to an operating ocean outfall. However, the reported times of survival and rates of reduction are significant in terms of the different conditions which they represent.

Tables 2 and 3, adapted from Pearson,(3) indicate the persistence or survival of pathogenic and coliform bacteria, respectively, in sea waters from various locations which were subjected to different treatments and methods of analysis. There is considerable evidence that, under some conditions, both pathogens and coliforms may survive for significant periods of time. That these conditions do not exist in nature is apparent from the reported details of the test procedures. Nevertheless, it is indicated that raw sea water provides a more hostile environment to enteric organisms than does filtered or sterilized sea water.

Evidence that coliforms are viable for longer periods than E. typhosa is reported by Beard and Meadowcroft(19) who found that coliforms survived for more than 35 days while E. typhosa survived for from 12 to 28 days. While these results are not necessarily valid for all pathogens, they indicate that the use of coliform bacteria determinations as indices of pollution is reasonable and, considering other available information, is probably a conservative method.

The various factors which have been suggested as being important in reducing bacterial populations may be divided into two general classifications as follows:

1. Bacteriological factors which are inherently present in the marine environment, including competition for available food, predation by protozoa or zooplankton, salinity, sunlight, temperature, pressure, bacteriophage, and heat-labile bactericidal substances. Evaluations of the relative effects of these factors may be found in the references cited above. For the purposes of this discussion, it is assumed that these factors operate universally in marine waters, and that they may be combined into a single factor, mortality. Included herein is the effect of breaking up by waves or surf of flocs or clumps of bacteria which, due to the nature of the MPN technique where either a single organism or a group of organisms could cause a positive tube reading, might superficially indicate an increase in bacterial population, although the actual numbers present would remain constant.(12)

2. Factors which are dependent upon the sewage, the type of sewage treatment and thus the previous history of the bacteria, and the initial dilution of the plant effluent as well as subsequent dilution of the mixture as it travels with the ocean currents. Of particular importance are the settling characteristics of the suspended solids in the effluent, within or upon which the bacteria are found.

Evaluation of Bacteriological Factors in Santa Monica Bay

Early in the period of investigation, it became apparent that the available information was inadequate to permit a reasonable analysis of the persistence of coliform bacteria from the proposed effluent in ocean waters. Thus, in situ studies were made by the Allan Hancock Foundation of the University of Southern California and the City of Los Angeles in the receiving waters surrounding the outfalls from the Hyperion plant, the Los Angeles County

TABLE 2

SURVIVAL OF PATHOGENIC BACTERIA IN SEA WATER (AFTER PEARSON[3])

Organism	Time of Survival		Investigator	Date	Sea Water		Experiments Conducted in	Remarks
	Ultimate Days	90% Reduction Hours			Source	Treatment		
Vibrio comma	81		Nicati & Rietch	1885	Marseilles Harbor	Sterilized	Laboratory	
	64		"	"	Open Sea	"	"	
	36		de Giaxa	1889	Bay of Naples	"	"	
	4		"	"	"	Raw	"	
	47		Jacobsen	1910	-	-	-	
	10		Kiribayashi & Aida	1934	Kellung Harbor, Formosa	Raw	Harbor	
	>10		"	"	"	"	Laboratory	
E. typhosa	25		de Giaxa	1889	Bay of Naples	Sterilized	"	
	9		"	"	"	Raw	"	
	14		Burdoni	1894	-	-	-	
	Several Weeks		Klein	1905	-	-	-	
	14-21		Soper	1909	-	-	-	
	12	19	Beard & Meadowcraft	1935	San Francisco Bay	Raw	S. F. Bay (1)	(1) Samples in semipermeable flasks suspended in natural bay water
	14	53	"	"	"	Filtered	"	
	28	22	"	"	"	Raw	"	
	>34	65	"	"	"	Filtered	"	
Typhoid	0.5-0.7		Trawinski	1929	-	-	-	
Paratyphoid	10		"	"	-	-	-	
Salmonella sp.	— (2)		Stryszak	1949	Gulf of Gdansk	Raw	-	(2) Reduction rate varied with temperature
Salmonella typhi		212 (3)	Buttiaux & Leurs	1953	English Channel	"	Laboratory	(3) Times for 90% reduction extrapolated from reported data
S. paratyphi B.		159 (3)	"	"	"	"	"	
S. typhi murium		— (4)	"	"	"	"	"	(4) Little reduction in 24 hours
S. enteridis		180 (3)	"	"	"	"	"	
Dysentery	0.5-0.7		Trawinski	1929	-	-	-	

TABLE 3

SURVIVAL OF COLIFORM BACTERIA IN SEA WATER (AFTER PEARSON[3])

(INCLUDES DATA REPORTED AS COLIFORM, E. COLI, AND SEWAGE BACTERIA)

Time for 90% Reduction, hours	Investigator	Date	Sea Water		Experiments Conducted in	Remarks
			Source	Treatment		
84	Beard & Meddowcroft	1935	San Francisco Bay	Raw	San Francisco Bay (1)	(1) Sample in semipermeable flasks suspended in natural water
98	"	"	"	Filtered	" (1)	
1.6	Zo Bell (2)	1936	Pacific Ocean	Raw	Ocean (1)	(2) Reported as "sewage bacteria"
2.8 (3)	"	"	"	Filtered	"	(3) Time for 90% reduction extrapolated from reported data
4.4 (3)	"	"	"	Autoclaved	"	
0.7 (3)	Carpenter, et al (2)	1938	-	-	-	
12 to 18 (3)	Weston & Edwards (2)	1939	Boston Harbor	Raw	Laboratory	
4	"	"	"	"	"	
18 to 34 (4)	Calif. Dept of Health	1942	Santa Monica Bay	Raw	"	(4) Time for 90% reduction interpolated from reported data
12 to 14 (4)	"	"	"	"	"	
23	Orlob	1949	Elliot Bay, Wash.	"	"	
46	Vaccaro, et al	1948	Vineyard Sound	"	"	
101	"	1949	"	"	"	
36	"	"	"	"	"	
34	"	"	"	"	"	
109 (5)	"	"	"	"	"	(5) Peptone added
550	"	"	"	Autoclaved	"	
218 (6)	"	"	"	Pasteurized	"	(6) 30 min @ 54°C
86 (7)	"	"	"	Chlorinated	"	(7) Dechlorinated
36	Williams	1950	Puget Sound	Raw	"	
30	"	"	"	"	Puget Sound (8)	(8) Samples in cellophane dialysis tubing suspended in Sound
18.2	Orlob	1951	Bud Inlet, Wash.	"	Laboratory	
84 (3,9)	"	"	"	"	"	(9) Incubated at 3°C
95	"	1953	Pacific Ocean @ San Francisco	"	"	
40	"	"	"	"	"	
22	"	"	"	"	"	
31 (4)	Moore	1954	North Devon, Gt.Brit	-	-	
34	Nusbaum & Garver	1954	San Diego Bay	Raw	Laboratory	
— (10)	"	"	"	Autoclaved	"	(10) No significant change in 8 days
108 (3,11)	"	"	"	Raw	San Diego Bay (12)	(11) Over 400% increase in 2 days, 87% mortality after 4 days
						(12) Samples in dialysis tubing suspended in Bay

Sanitation Districts' plant, the Orange County Sanitation Districts' plant, and the City of Los Angeles Terminal Island Treatment Plant.

Samples were taken from areas within the particular sewage field, which were marked by fluorescein dye, current crosses, or other suitable means, at regular intervals for as much as 26 hours during which the dye patch moved away from the outfall. Determinations of the most probable number (MPN) of coliform densities were made in accordance with Standard Methods[20] for lactose-broth presumptive tests using 2 tubes in each of 3 decimal dilutions and brilliant green bile confirmations.

These studies were directed primarily towards determination of the overall rate of disappearance of coliforms in order that the effects of effluents discharged offshore could be evaluated. However, additional observations directed towards determining the net dilution of the effluent were also made. Dilutions have been studied by means of a radioactive tracer,[8] which permitted calculations of dilutions of as high as 10,000 parts of sea water to 1 of effluent, and by determinations of salinity which may be used to calculate dilutions of up to about 300 to 1. The results of these studies are indicated on Figure 6, based upon results obtained by the two investigating organizations.[4,8]

A considerable variation in the persistence of coliform bacteria from the several outfalls is thus indicated. It should be noted that the studies at Hyperion were conducted for periods of up to 26 hours, while those at other outfalls were for periods of up to about 6 or 8 hours. However, there was no significant variation in the overall rates of reduction at Hyperion over the entire period, so that results obtained at the other locations are assumed to have essentially the same validity.

The persistence of coliform bacteria in sea water may be formulated in accordance with the following:[21]

$$\frac{N_t}{N_o} = 10^{-\frac{t}{T\text{-}90}}$$

where N_t = number of survivors after t hours

N_o = initial population at t = 0

T-90 = time for 90% reduction in bacterial density

The overall reduction is assumed to follow the relationship:

$$\frac{1}{T\text{-}90_{o/a}} = \frac{1}{T\text{-}90_m} + \frac{1}{T\text{-}90_d} + \frac{1}{T\text{-}90_s}$$

where $T\text{-}90_{o/a}$ = Observed time for 90% reduction.

$T\text{-}90_m$ = Time for 90% reduction due to mortality as defined above.

$T\text{-}90_d$ = Time for 90% reduction due to dilution of the field as it moves down-current.

$T\text{-}90_s$ = Time for 90% reduction due to sedimentation

It is possible to make approximations of the various T-90's in Santa Monica Bay. As stated earlier, the overall T-90 is essentially constant for the period of about one day which is of significance at Hyperion because of

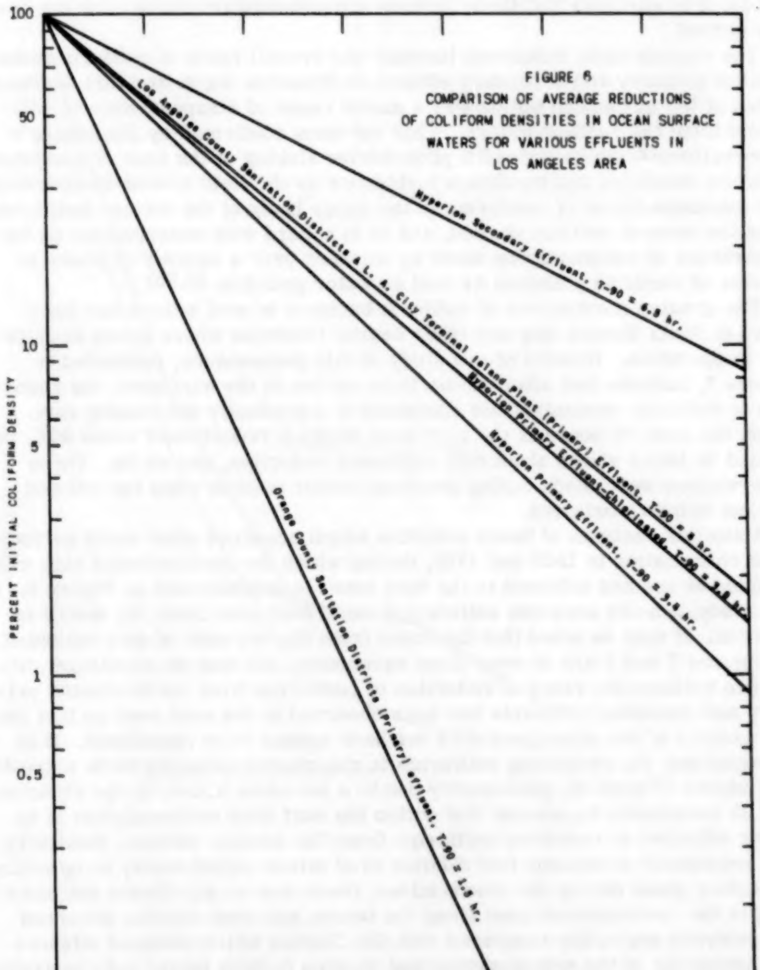


FIGURE 6
COMPARISON OF AVERAGE REDUCTIONS OF COLIFORM DENSITIES IN OCEAN SURFACE WATERS FOR VARIOUS EFFLUENTS IN LOS ANGELES AREA

the general currents and circulation of the bay. Thus, in order to evaluate the relative effects of the various factors which serve to reduce coliform densities in the surface waters which are of the greatest sanitary significance, it is assumed that these factors are essentially constant for the one day period.

The considerable difference between the overall rates of coliform reduction for primary and secondary effluent at Hyperion suggested that sedimentation of the suspended solids was a major cause of disappearance of coliforms from the surface waters. This has been confirmed by Rittenberg's observations[8] which showed a progressive sinking of the zone of maximum coliform densities and maximum turbidities as the field moved downstream and extensive fields of coliforms in the upper layer of the bottom sediments near the several outfalls studied, and is in accord with observations on the importance of sedimentation made by workers over a number of years in studies of shellfish pollution as well as water pollution.[3,25]

The greater persistence of coliform bacteria in surf waters has been noted in Santa Monica Bay and other nearby locations where ocean outfalls are in operation. Results of one study of this phenomenon, presented in Figure 7, indicate that after the bacteria arrive in the surf zone, the reduction in coliform concentrations continues at a gradually decreasing rate. Thus, the first 24 hours in the surf zone shows a reduction of some 90%, the second 24 hours shows about 80% additional reduction, and so on. These observations were made during previous winter months when the effluent was not being chlorinated.

A similar analysis of beach pollution which occurred after short periods of no chlorination in 1955 and 1956, during which the unchlorinated slug was sampled at sea and followed to the surf zone, is summarized on Figure 8. In this study, a more accurate estimate of the travel time from the outfall is possible. It may be noted that the rates from the two sets of data indicated on Figures 7 and 8 are in very close agreement, and that no significant difference between the rates of reduction of coliforms from unchlorinated primary and secondary effluents has been observed in the surf zone so that the past history of the organisms does not here appear to be significant. It is indicated that the remaining coliforms in chlorinated effluents show a greater persistence (Figure 6), presumably due to a selective action by the chlorine.

It is reasonable to assume that within the surf zone sedimentation is no longer effective in removing coliforms from the surface waters. Similarly, it is reasonable to assume that dilution is of minor significance; no upwelling was taking place during the observations, there was no significant net movement of the contaminated zone along the beach, and what dilution occurred was probably negligible compared with the dilution which obtained offshore.

Elimination of the sedimentation and dilution factors leaves only mortality. It is probable that the various contributing factors which cause mortality vary among themselves but the combined effect seems to be fairly uniform. With this in mind, the curve shown on Figure 8 has been extrapolated backward in order to obtain a reasonable approximation of the mortality T-90 for the first 24-hour period referred to earlier. Thus $T\text{-}90_m$ is indicated to be about 17.8 hours. This figure necessarily includes any effect of breaking up of clumps of coliforms by wave or surf action which, as mentioned earlier, might result in a superficial increase in the MPN. Such a phenomenon, while it has not been evaluated for the Hyperion discharge, would imply a higher true coliform density at the boil than the observed values. Thus, assuming

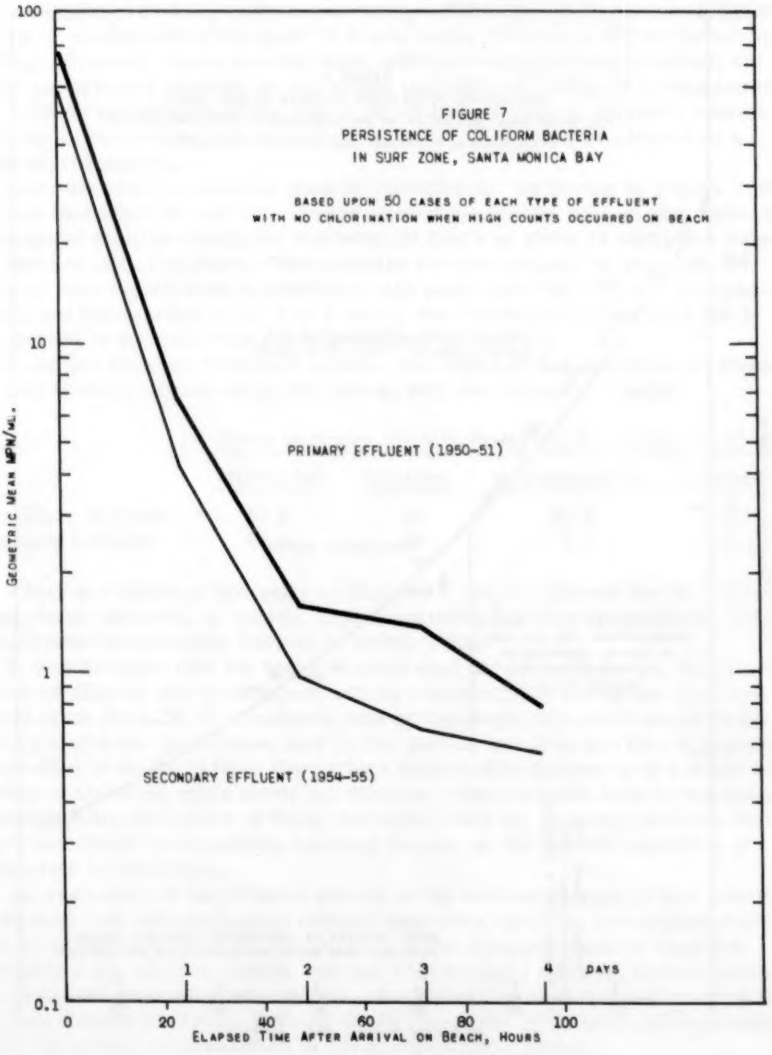


FIGURE 7
PERSISTENCE OF COLIFORM BACTERIA
IN SURF ZONE, SANTA MONICA BAY
BASED UPON 50 CASES OF EACH TYPE OF EFFLUENT
WITH NO CHLORINATION WHEN HIGH COUNTS OCCURRED ON BEACH
PRIMARY EFFLUENT (1950-51)
SECONDARY EFFLUENT (1954-55)
GEOMETRIC MEAN MPN/ML.
100
10
1
0.1
1
2
3
4
DAYS
0
20
40
60
80
100
ELAPSED TIME AFTER ARRIVAL ON BEACH, HOURS

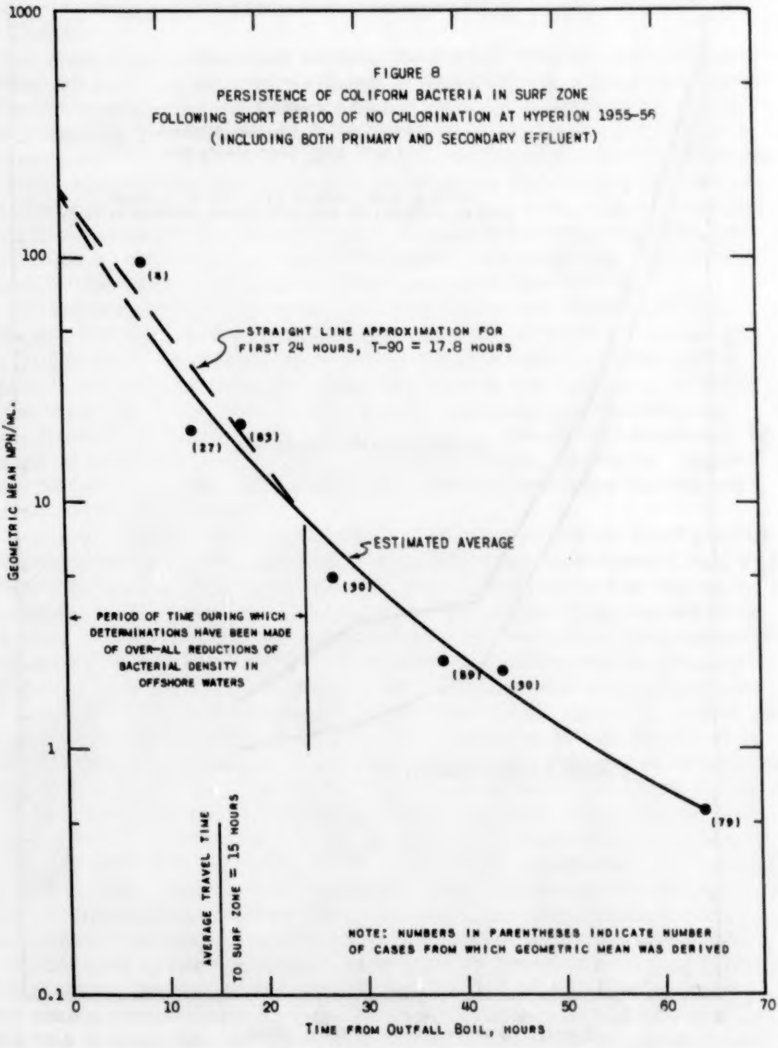


FIGURE 8
PERSISTENCE OF COLIFORM BACTERIA IN SURF ZONE
FOLLOWING SHORT PERIOD OF NO CHLORINATION AT HYPERION 1955-56
(INCLUDING BOTH PRIMARY AND SECONDARY EFFLUENT)
STRAIGHT LINE APPROXIMATION FOR FIRST 24 HOURS, T-90 = 17.8 HOURS
ESTIMATED AVERAGE
PERIOD OF TIME DURING WHICH DETERMINATIONS HAVE BEEN MADE OF OVER-ALL REDUCTIONS OF BACTERIAL DENSITY IN OFFSHORE WATERS
AVERAGE TRAVEL TIME TO SURF ZONE = 15 HOURS
NOTE: NUMBERS IN PARENTHESES INDICATE NUMBER OF CASES FROM WHICH GEOMETRIC MEAN WAS DERIVED
(8)
(27)
(83)
(30)
(89)
(30)
(79)
GEOMETRIC MEAN MPN/ML.
1000
100
10
1
0.1
0
10
20
30
40
50
60
70
TIME FROM OUTFALL BOIL, HOURS

that the disintegration of clumps is progressive as the sewage field moves downstream, a lower value for the $T\text{-}90_m$ would result since the true coliform density would approach the observed density with the passage of time. For example, a 10-fold apparent increase in MPN due to the complete breaking up of clumps within the first 24 hours would result in a 50% reduction in $T\text{-}90_m$. However, since several other unknown variables are involved, and since the primary purpose of estimating the value of $T\text{-}90_m$ is to determine the relative importance of the major factors which reduce coliform concentrations in surface waters, the higher value of 17.8 hours is adopted as a first approximation.

Next, the effect of dilution must be considered. Referring to Figure 2, it is seen that after the initially diluted effluent leaves the boil, it undergoes a subsequent dilution during the following 24 hours of about 14 parts sea water per part of initial mixture. Disregarding for the moment the fact that the dilution rate varies from a relatively high value near the boil to a comparatively low figure after some 3 to 4 hours, the cumulative effect over the 1-day period is equivalent to a $T\text{-}90_d$ of about 20 hours.

Using the formula developed earlier, the effect of sedimentation at Hyperion may then be calculated by difference, with the following results:

	Time in Hours for 90% Reduction in Coliforms (T-90)			
	Mortality	Dilution	Sedimentation	Overall
Secondary Effluent	17.8	20	21.0	6.5
Primary Effluent	17.8	20	5.3	3.4

These are shown graphically on Figures 9 and 10. Except for the overall reductions, they are, of course, approximations, but they are believed to be reasonable and probably correct to within ± 50%.

It may be noted that the analysis presented herein neglects (1) the greater effect of dilution due to turbulent mixing which obtains during the first few hours from the boil, (2) a reduced rate of sedimentation which would result from the greater turbulence, and (3) the partial isolation and thus a possible protection of bacteria from the various bactericidal factors in sea water by virtue of clumping and a lower net dilution. The available data do not permit a satisfactory evaluation of these variables; they do, however, indicate that their net effect is essentially constant insofar as the overall reduction of coliforms is concerned.

An evaluation of the relative effects of the various factors is now possible. It is seen that with secondary effluent mortality, dilution, and sedimentation are of essentially the same importance in the disappearance of coliform bacteria from surface waters, but that with primary effluent, sedimentation is by far the most important factor. A similar analysis of the data from the Orange County Sanitation District Outfall reported by Rittenberg[8] indicates that, there too, sedimentation is the predominating factor.

Since sedimentation is shown to be a significant factor in disappearance of coliforms from surface waters, it follows that resuspension of the settled particles might cause pollution of overlying waters. Another possibility which might be considered is the behavior of grease sleeks or surface films which, being wind-driven, could carry concentrations of bacteria to the surf zone in relatively short periods of time.[12] These factors can be discounted in Santa Monica Bay since it has been possible to account for the location and

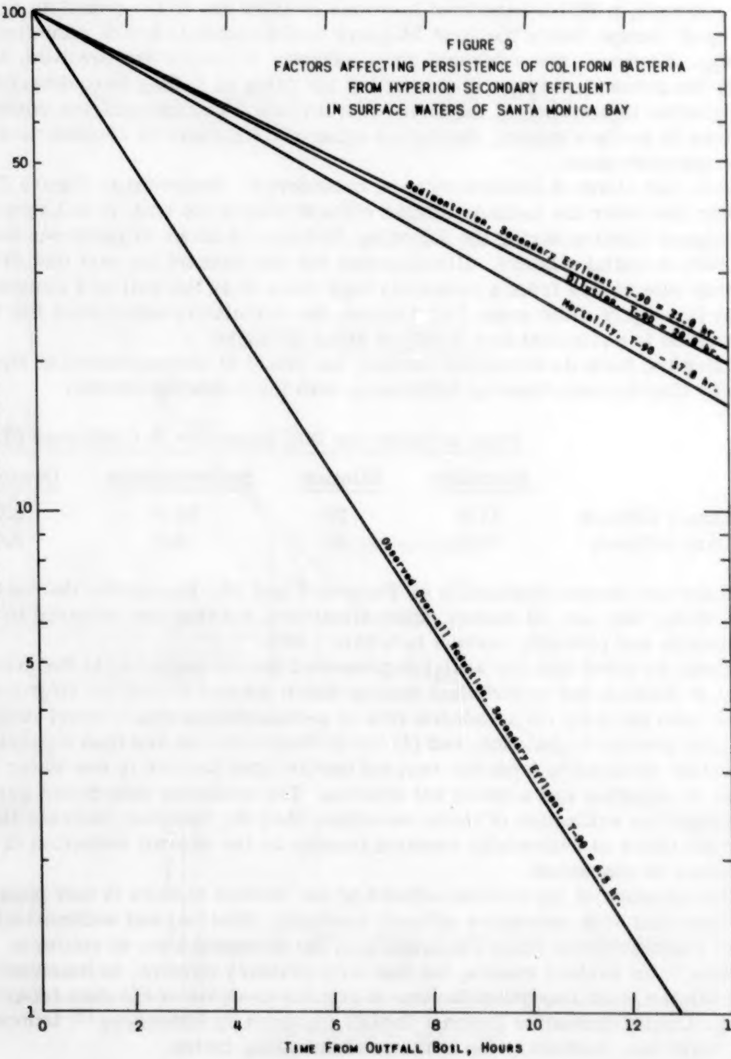


FIGURE 9
FACTORS AFFECTING PERSISTENCE OF COLIFORM BACTERIA
FROM HYPERION SECONDARY EFFLUENT
IN SURFACE WATERS OF SANTA MONICA BAY
Sedimentation, Secondary Effluent, T-90 = 31.0 hr.
Dilution, T-90 = 20.0 hr.
Mortality, T-90 - 17.8 hr.
Observed Over-all Reduction, Secondary Effluent, T-90 = 6.5 hr.
100
50
10
5
1
0
2
4
6
8
10
12
14
Percent Initial Coliform Density
Time From Outfall Boil, Hours

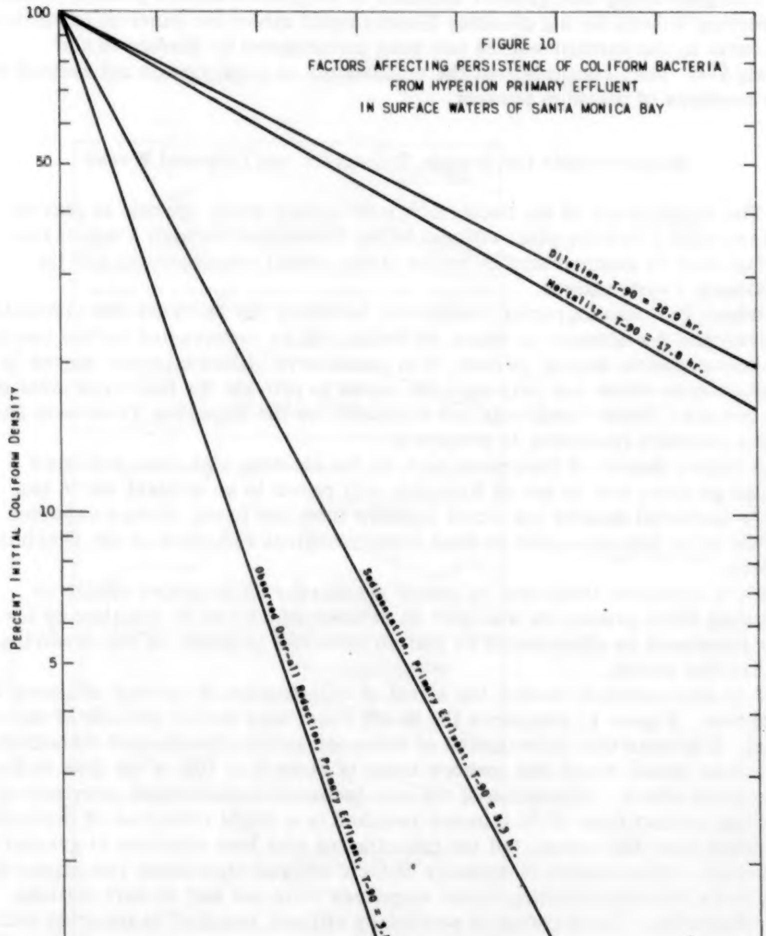


FIGURE 10
FACTORS AFFECTING PERSISTENCE OF COLIFORM BACTERIA
FROM HYPERION PRIMARY EFFLUENT
IN SURFACE WATERS OF SANTA MONICA BAY

intensity of observed coliform densities in the surf waters entirely from the movements of the sewage field in the water itself.

The possibility that greater amounts of suspended matter present in the receiving waters during plankton blooms could affect the survival of coliform bacteria in the surface waters has been investigated by Stevenson and Resig.[11] They conclude that the persistence of coliforms is not related to the numbers of plankton present.

Requirements for Sewage Treatment and Disposal Works

The significance of the bacteriological factors which operate in marine waters upon a sewage plant effluent being discharged through a submarine outfall may be summarized in terms of the outfall requirements and the treatment requirements.

Where the oceanographic conditions, including the currents and circulation pattern and the distance to which an outfall can be constructed before reaching unreasonable depths, permit, it is possible to utilize a lesser degree of treatment on shore and rely upon the ocean to provide the final treatment of the sewage. These conditions are indicated for the Hyperion Treatment Plant where primary treatment is proposed.

A higher degree of treatment such as the existing high-rate activated sludge process now in use at Hyperion will result in an effluent which has lower bacterial density but which appears from the ocean studies reported herein to be less amenable to final bacteriological reduction in the receiving waters.

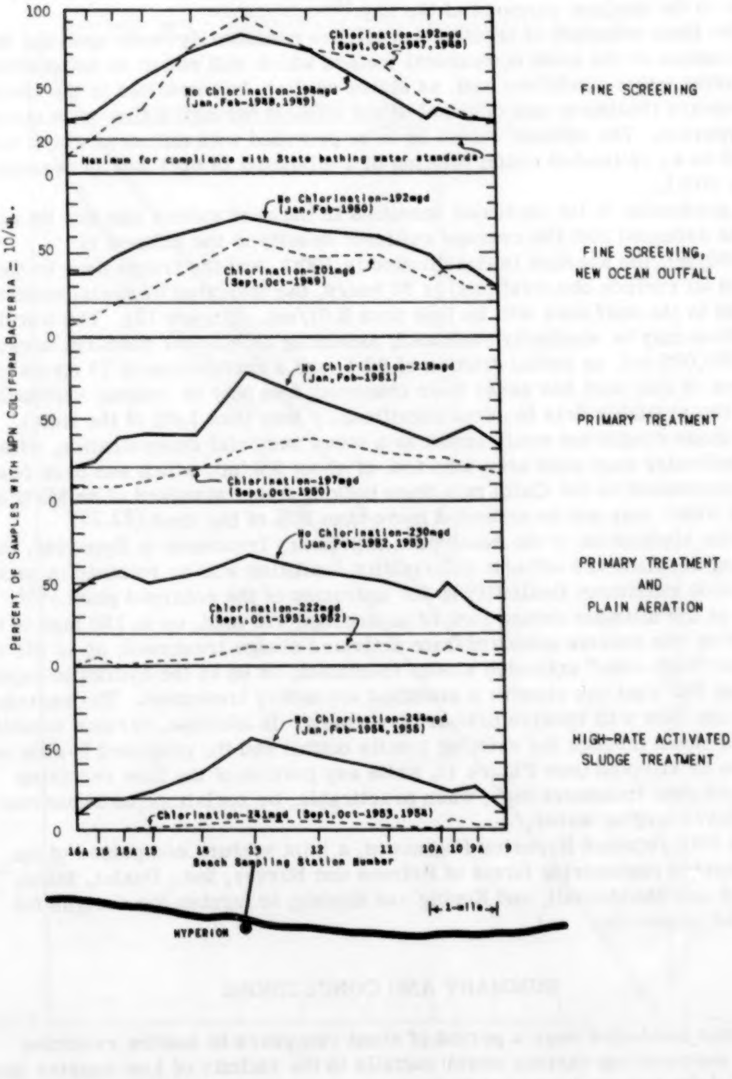
More complete treatment by either standard-rate activated sludge or trickling filter processes will give an effluent which can be polished by further treatment or chlorinated so that no bacterial pollution of the receiving waters can result.

It is interesting to review the effect of chlorination of various effluents at Hyperion. Figure 11 compares the beach conditions during periods of chlorination. It is seen that chlorination of screened sewage discharged through the old ocean outfall which had inshore leaks of some 5 to 10% of the flow had no significant effect. Utilization of the new (present) outfall which provided an average contact time of 30 minutes resulted in a slight reduction of coliform densities near the outfall, but the chlorination was less effective at greater distances. Chlorination of primary effluent showed significant reductions of coliforms, but State bathing water standards were not met at surf stations near Hyperion. Chlorination of secondary effluent resulted in reducing coliform concentrations to permissible levels. It may be noted that the 18 to 20 tons per day of chlorine used in 1947-48 was reduced to 6 to 8 in 1955.

A comparison from Figure 11 of the effects of unchlorinated effluents from primary and high-rate activated sludge indicates that about a 35% reduction in beach pollution was obtained with the latter. The discrepancy between experience on the beach and the data obtained from reproducible experiments in the water has not been entirely resolved. It should be noted, however, that the periods of non-chlorination were during winter (wet-weather) months and that the effect of runoff must be considered. It is unreasonable to assume that aeration of primary effluent would lower its bacteriological quality as indicated by the beach pollution data shown on Figure 11; thus, the effect of runoff was probably a major contributing factor. A quantitative evaluation of

FIGURE 11

EFFECT OF CHLORINATION OF EFFLUENTS FROM HYPERION TREATMENT PLANT



beach pollution from runoff is not possible from presently available data. Qualitatively, however, it can be stated that such pollution is determined by the frequency, intensity, and duration of rains and that major drains, such as the one discharging near Station 10, show a pronounced effect upon beach pollution. Other factors which are significantly variable during the winter months are oceanographic, resulting in variations in current direction indicated by beach pollution data obtained daily since March, 1946,[7] and meteorological, wherein winds directed offshore are of considerable importance in the surface currents of the bay.[5]

The final selection of treatment facilities necessarily rests upon the determination of the most economical method which will result in satisfactory receiving water conditions and, as stated earlier, has resulted in the choice of primary treatment and disposal of the effluent through a five-mile outfall at Hyperion. The effluent outfall is to be provided with diffusers which will result in an estimated initial dilution of a minimum of 60:1 and an average of some 200:1.

A prediction of the bacterial densities in the surf waters can now be made. If it is assumed that the average coliform density in the effluent is 500,000/ml, the average initial dilution is 100:1, and the travel time to shore (based on surface observations) is 20 hours, the indicated bacterial concentration in the surf zone will be less than 0.01/ml. (Figure 12). The worst condition may be similarly evaluated, assuming an effluent coliform density of 1,000,000/ml, an initial dilution of 60:1, and a travel time of 13 hours (a current of this sort has never been observed, and may be roughly estimated from the available data to occur significantly less than 1.0% of the time). Even these conditions would result in a mean bacterial concentration, within the particular surf zone area affected, of about 2.5/ml, which has been found to be equivalent to the California State bathing water standard of an MPN of 10/ml which may not be exceeded more than 20% of the time.[22,23]

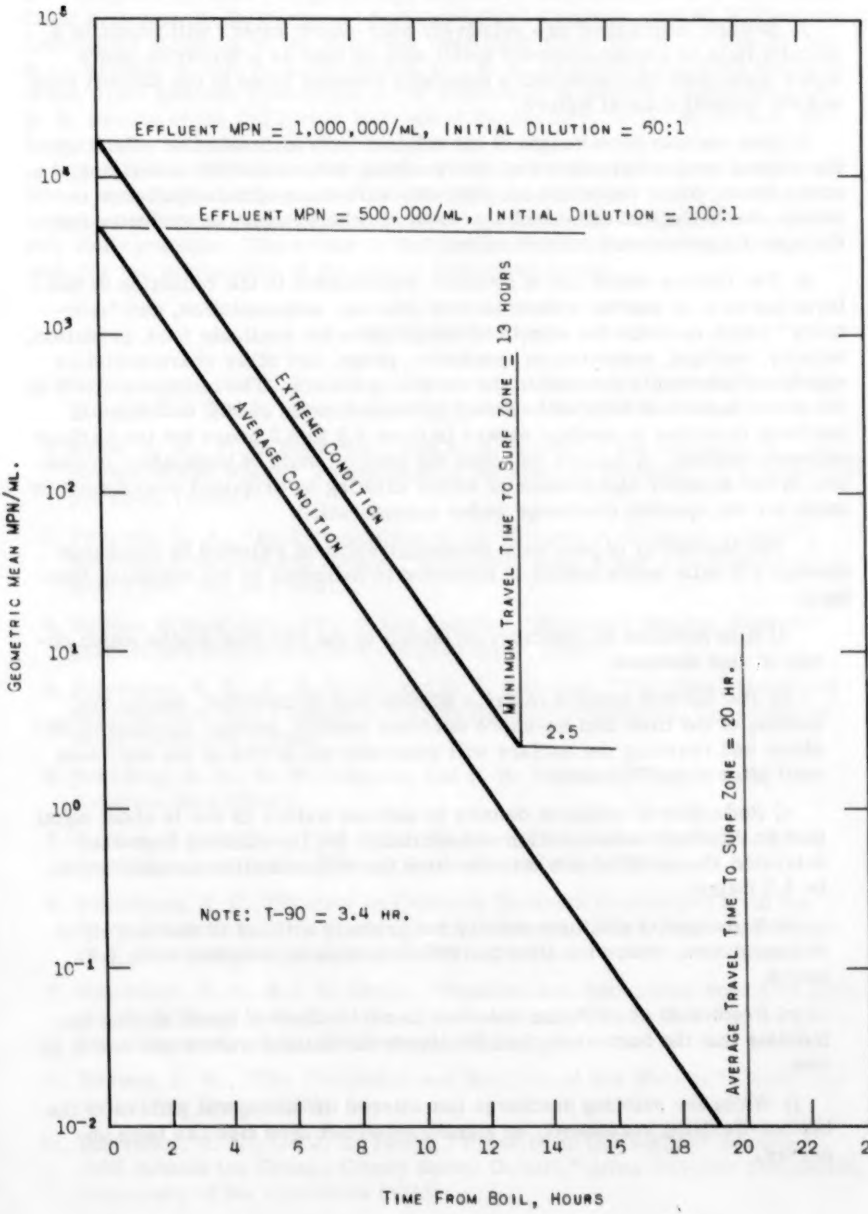
In the application of the basic plan of primary treatment at Hyperion, the existing aeration and effluent chlorination facilities will be retained in order to provide maximum flexibility in the operation of the enlarged plant.[24] Thus, at the ultimate design flow of an average 420 mgd, up to 120 mgd of the total flow can receive standard-rate activated sludge treatment; up to 245 can receive "high-rate" activated sludge treatment; or up to the hydraulic capacity of about 315 mgd can receive a modified secondary treatment. The remainder of the flow will receive primary treatment. In addition, various combinations of flows through the existing 1-mile outfall and the proposed 5-mile outfall can be effected (see Figure 1), while any portion of the flow receiving standard-rate treatment may, when practicable, be reclaimed as industrial or ground-recharging water.

The City retained Hyperion Engineers, a joint venture comprised of the Los Angeles engineering firms of Holmes and Narver, Inc.; Daniel, Mann, Johnson and Mendenhall; and Koebig and Koebig; to furnish the designs for the plant expansion.

SUMMARY AND CONCLUSIONS

Studies conducted over a period of about two years in marine receiving waters surrounding various sewer outfalls in the vicinity of Los Angeles have indicated the following general findings:

FIGURE 12
APPLICATION OF OVER-ALL BACTERIAL REDUCTION RATE TO PROPOSED HYPERION PRIMARY EFFLUENT DISCHARGED 5 MILES OFFSHORE



1. After the sewage undergoes an initial dilution as measured at the top of the rising column, additional dilution will derive from turbulent mixing which, at Hyperion, is effective for some 4 hours and from lateral diffusion thereafter.

2. Sewage discharged into relatively near-shore waters will result in a distinct field of a comparatively small size as well as a larger in-shore water mass with characteristics generally between those of the distinct field and the normal coastal waters.

3. The various constituents of the effluent have a measurable effect upon the normal ecological pattern of the receiving waters and the underlying ocean floor. Since there are considerable variations of these patterns in nature, the biological effects of any waste discharge must be evaluated for the specific area under consideration.

4. The factors which are of primary significance in the reduction of coliform bacteria in marine waters include dilution, sedimentation, and "mortality" which includes the effects of competition for available food, predation, salinity, sunlight, temperature, pressure, phage, and other characteristics which are inherently present in the receiving waters. The combined effect of the above factors is such as to result in overall rates of 90% reduction in coliform densities in surface waters in from 1.5 to 6.5 hours for the various effluents studied. It follows that with the present state of knowledge, evaluation of the sanitary significance of either existing or proposed works must be made for the specific discharge under consideration.

5. The feasibility of providing primary treatment followed by discharge through a 5-mile ocean outfall at Hyperion is indicated by the following findings:

a) It is possible to construct an outfall in the 190-foot depths which obtain at that distance.

b) The current pattern in Santa Monica Bay is such that, during that portion of the time that on-shore currents prevail, sewage discharged offshore and reaching the surface will generally not arrive at the surf zone until after some 20 hours.

c) Reduction of coliform density in surface waters is due in about equal part to dilution, sedimentation and mortality for the existing high-rate activated sludge effluent where the time for 90% reduction is indicated to be 6.5 hours.

d) Reduction of coliform density for primary effluent is due largely to sedimentation, where the time for 90% reduction is indicated to be 3.4 hours.

e) Prediction of coliform densities in surf waters of Santa Monica Bay indicate that the bacteriological standards for bathing waters can easily be met.

f) While the existing discharge has altered the biological pattern of the bottom-dwelling organisms, no significant effect upon fish has been observed.

ACKNOWLEDGMENTS

Appreciation is expressed to W. A. Schneider and N. B. Hume, Director and Assistant Director, respectively, Bureau of Sanitation; G. A. Parkes, Chief Engineer, R. D. Bargman, Assistant Chief Engineer, and W. F. Garber, Laboratory Director, of the Hyperion Treatment Plant; Dr. K. O. Emery, Dr. S. C. Rittenberg, Dr. R. E. Stevenson, Dr. R. B. Tibby, and Dr. Olga Hartman of the Allan Hancock Foundation of the University of Southern California; Dr. N. H. Brooks of the California Institute of Technology; Dr. C. E. ZoBell, Dr. D. L. Inman, and Mr. J. D. Frautschy of the Scripps' Institution of Oceanography; and D. L. Narver, Jr., Project Manager, and R. R. Alvy, D. R. Miller, and C. H. Lawrence of Hyperion Engineers; whose participation, assistance, and suggestions throughout the period of investigation have made this study possible. The writer is indebted to B. L. Jones, Bureau of Sanitation, for the preparation of the charts and tables herein.

REFERENCES

1. Rawn, A. M., and H. K. Palmer, "Pre-determining the Extent of a Sewage Field in Sea Water," Trans. ASCE 94, 1036-1060 (1930).
2. Rawn, A. M., F. R. Bowerman, and N. H. Brooks, "The Diffusion of Sewage in Sea Water," Prepublication manuscript reviewed by Pearson,(3) pp. 60-61 (1956).
3. Pearson, E. A., "An Investigation of the Efficacy of Submarine Outfall Disposal of Sewage and Sludge," California State Water Pollution Control Board Pub. No. 14 (1956).
4. Bureau of Sanitation, City of Los Angeles, "Summary Report, Oceanographic Investigation of Santa Monica Bay." (1956)
5. Stevenson, R. E., R. B. Tibby, and D. S. Gorsline, "The Oceanography of Santa Monica Bay, California," Allan Hancock Foundation, University of South California (1956).
6. Sverdrup, H. U., M. W. Johnson, and R. H. Fleming, "The Oceans," Prentice-Hall (1946).
7. Bureau of Sanitation, City of Los Angeles, "Progress Report No. 3, Oceanographic Investigation of Santa Monica Bay" (1955).
8. Rittenberg, S. C., "Studies on Coliform Bacteria Discharged from the Hyperion Outfall, Final Bacteriological Report," Allan Hancock Foundation, University of Southern California (1956).
9. Stevenson, R. E., & J. R. Grady, "Plankton and Associated Nutrients Surrounding Three Outfalls in Southern California," Allan Hancock Foundation, University of So. California (1956).
10. Harvey, H. W., "The Chemistry and Fertility of Sea Waters," Cambridge University Press (1955).
11. Stevenson, R. E., and J. M. Resig, "Plankton in the Summer Months of 1956 Around the Orange County Sewer Outfall," Allan Hancock Foundation, University of So. California (1956).

12. Horrer, P. L., et al, "Sewage in Santa Monica Bay: A Critical Review of the Oceanographic Studies," Marine Advisers, P. O. Box 1001, La Jolla, California (1956).

13. Hartman, Olga, "Results on Investigations of Pollution and Its Effects on Benthonic Populations in Santa Monica Bay, California," Allan Hancock Foundation, University of So. California (1956).

14. Hartman, Olga, "Contributions to a Biological Survey of Santa Monica Bay, California," Allan Hancock Foundation, University of So. California (1956).

15. Moore, B., "Sewage Contamination of Coastal Bathing Waters," Bull Hygiene 29 (7): 689 - 704, (1954).

16. Greenberg, A. E., "Survival of Enteric Organisms in Sea Water," Public Health Reports 71 (1), 77-86, (1956).

17. Orlob, G. T., "Viability of Sewage Bacteria in Sea Water," Sewage and Industrial Wastes 28 (9): 1147 - 1167, (1956).

18. Terry, R. D., "An Annoted Bibliography on Bacteriology, Oceanography, and Marine Geology as They Relate to the Disposal of Waste Material into the Sea," Allan Hancock Foundation, University of Southern California (1956).

19. Beard, P. J., and N. F. Meadowcroft, "Survival and Rate of Death of Intestinal Bacteria in Sea Water," American Journal Pub. Health 25: 1023 - 1026 (1935), reviewed by Pearson (3), pp. 34-41.

20. APHA, AWWA & FSIWA, "Standard Methods for the Examination of Water, Sewage, and Industrial Wastes," 10th Ed., American Pub. Health Assoc. (1955).

21. Chick, H., "Investigation of the Laws of Disinfection" J. Hyg. 10: 237 (1910). Reviewed by Pearson,(3) pp. 39-42.

22. Bureau of Sanitation, Department of Public Works, City of Los Angeles, Annual Report for 1952-53.

23. Garber, W. F., "Bacteriological Standards for Bathing Waters," Sew. & Ind. Wastes 28 (6), 795-808 (1956).

24. Theroux, Robert J., "Enlarged Sewage Disposal Facilities for Los Angeles," Sew. & Ind. Wastes 29 (2), 124-133 (1957).

25. Zo Bell, Claude E., "Marine Microbiology," Chronica Botanica (1946).

Journal of the

SOIL MECHANICS AND FOUNDATIONS DIVISION

Proceedings of the American Society of Civil Engineers

SED RESEARCH REPORT NO. 14

On A SURVEY OF THE PRESENT STATUS OF REFUSE ENGINEERING RESEARCH AND DEVELOPMENT

By Refuse Engineering Section of the Sanitary Engineering Research Committee.

Acknowledgement The Sanitary Engineering Division gratefully recognizes the generosity and professional courtesy of the many authorities providing data and information to the Refuse Engineering Section of the Research Committee.

SYNOPSIS

The results of several years investigation to ascertain the present professional status of refuse collection and disposal activities in the United States and abroad are summarized and critically evaluated. Data concerning new developments and recommendations for improved practices are reviewed. A previous preliminary report was prepared and has presented further detailed information that is not repeated in this paper.[1]

INTRODUCTION

The Refuse Engineering Section of the SED Research Committee has for three years (1955-57) been actively surveying the present status of Refuse Engineering. Representative authorities were contacted either personally or by letter questionnaire to obtain information concerning the following: (1) the extent of current refuse engineering research and development work, and (2)

Note: There will be no discussion. Paper 1539 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. SA 1, February, 1958.

1. SED Research Report No. 11: Status of Refuse Collection and Disposal, 1176, Journal of the San. Engr. Div., Proceed. ASCE, Vol. 83, 1176-1 to 1176-7, Feb. 1957.

recommendations for additional research and development projects and programs which should be undertaken. Many authorities too numerous to list in this report have generously contributed their knowledge.

A preliminary published report describes detailed recommendations for improvement in the present practice of refuse engineering. The results of this initial study by the Refuse Engineering Section are available as SED Research Report No. 11 and are not repeated for the sake of brevity.[1] This final report is concerned primarily with the general status of refuse engineering and secondarily with detailed recommendations.

The information presented in this report is categorized in accordance with the location of the authorities under the general headings: (1) International Refuse Engineering Activities, (2) Federal Government Work, (3) State Health Departments, (4) Suburban and Municipal Activities, (5) Universities, and (6) Other Professional Refuse Engineering Activities Supported by Professional Publications, Associations and Professional Societies and Private Consulting Engineers.

International Refuse Engineering Activities

The Institute of Public Cleansing, Great Britain, has launched a program of research on 15 subjects. These include: dustbins, containers, etc.; influence of frequency of collection upon cost; a formula for adjusting costs of different locations, etc.; petrol vs. diesel oil; problems of maintenance; concentrated kitchen waste; waste paper collection; sorting and baling of waste paper; controlled tips; mechanical sweeping; transfer plants; plant requirements at refuse disposal works; salvage potential; protective clothing; and composting.

The aforementioned research program was instituted two years ago and one report has been produced on the "Frequency of Refuse Collection". Mr. K. Wyndham Brown, Secretary of the Institute of Public Cleansing stated that the research investigations concerning concentration of kitchen wastes have been discontinued. He also reported that Professor Dr. O. Jagg is Secretary for an International Working Party on Composting.

The United Nations World Health Organization does not carry out directly any research activities in the field of refuse engineering; however, the UNWHO is cooperating with the Japanese Government in a program of composting both municipal refuse and night soil at Kobe, Japan. Mr. H. G. Baity, Director, Division of Environmental Sanitation, UNWHO, also advised that a small amount of work has been undertaken by the Dino Corporation at Ruschlikon, Switzerland, to determine the feasibility of applying ammonia or other nitrogen components in order to build up compost nitrogen content.

Mr. Paul Bierstein, Regional adviser on Environmental Sanitation, UNWHO, Manila, Philippine Islands, states that the Kobe, Japan, composting project has progressed from pilot plant to full-scale operations during the first part of 1957 and that further progress data is being collected. He also reported that a full-scale composting plant was constructed at Seoul, Korea, without benefit of pilot plant studies.

The Netherlands has been a leader in the development of improved refuse disposal practices. Mr. W. A. G. Westrate, Engineer, reported that in Europe the major engineering developments are generally the result of progress derived from trying new methods out in practice rather than the result of

research projects. He states that in The Netherlands and in Switzerland, the standardized refuse collection can has been in widespread use for the last twenty years. In The Netherlands, 80 per cent of the total refuse is collected in such containers which fit into a device on the collection vehicle so that the loading of the vehicle takes place without any dust production, or loss by wind blowing away papers and other refuse. Westrate indicates that refuse dumps are being abandoned and that composting, incineration, and sanitary land fill are receiving increasing acceptance. The refuse collection vehicles in The Netherlands are commonly of the rolling drum type with re-loading in which the contents are transported into the rear of the collector from the front. The compaction type collection equipment commonly used in the United States has not proven practical in The Netherlands because of their high ash content (330 lbs. per cubic yard) whereas the American refuse is much lighter and therefore will compact more readily.

Westrate further states that there are 8 composting plants in The Netherlands, 5 of which employ a rasping system for sizing and processing the composted refuse. The V. A. M. Company, a government financed Netherlands Corporation, in conjunction with the research foundation composting are working closely together in order to develop improved composting machinery. Westrate indicates that in The Netherlands there is considerable investigation of the possibilities for composting refuse and sewage sludge. The Netherlands compost is largely employed in horticulture, where it is used as a heating manure following the addition of about 3 per cent lime and 0.4 per cent sulphur. The Dutch also employ compost as a conventional humus source for agriculture.

In South Africa, the Soil Conservation Board of the South African Council for Scientific Industrial Research is at present investigating municipal waste utilization. Mr. P. R. Krige, Senior Research Officer, National Chemical Research Laboratories, reports that in South Africa there are special investigations concerned with: (1) The economies of salvaging refuse by means of refuse sorting and developing a market potential for such items; (2) conversion of organic components of refuse to compost with the aid of sewage sludge and/or night soil; and (3) mechanization of the composting process. Mr. Krige further stated that the City of Johannesburg, on the basis of extensive research, has developed a large refuse transfer station to handle 300 tons per day.

United States Government Work

The Robert A. Taft Sanitary Engineering Center of the United States Public Health Service, is at present performing joint research with the United States Bureau of Mines concerning the combustion of refuse. The research objective is to investigate and correlate the relationship of incinerator design criteria with performance characteristics and in particular to minimize the discharge of atmospheric contaminants. This work is divided into two broad phases: (1) Prototype studies under controlled experimental conditions, and (2) field studies of conventional incinerators under normal operating conditions.

The United States Atomic Energy Commission is supporting a development project for a special incinerator to handle combustible radioactive contaminated materials. This work at Harvard University is primarily concerned with obtaining information on the air cleaning components required for such a

special incinerator unit developed by the United States Bureau of Mines at the Central Experiment Station in Pittsburgh, Pennsylvania. A second A. E. C. Project exists at Knolls Atomic Power Laboratory on the compression of combustible solid radioactive wastes in order to reduce their volume and facilitate shipment of these materials off-site.

The United States Public Health Service is also supporting field composting studies at Phoenix, Arizona, and pilot plant investigations at Savannah, Georgia.

State Health Departments

The State of Connecticut Health Department has prepared a comprehensive booklet describing the status of Municipal Refuse Disposal in Connecticut, but like most other state departments of health in the United States, there is a minimal refuse engineering program.

The State of Indiana Health Department reports that development of the "Jasper Plan", which the City of Jasper, Indiana, has instituted employs the use of private individual garbage grinders in each home as a means of garbage disposal. A summary survey of certain local community refuse experience has been prepared by The State Health Department and lists: The collection frequency for garbage and trash collection and the disposal method.

The Division of Sanitation, State of Nebraska Department of Health, reports that there are three raw sewage sludge filtration projects under consideration in Nebraska. This sludge will be required to be buried in a sanitary land fill.

The 19 State Health Departments that replied to the questionnaire reported that they have no knowledge of other special refuse engineering research and development projects being undertaken in their areas. A need for further refuse engineering development programs is evident.

Suburban and Municipal Activities

A canvass of representative American Municipalities indicates that little research and development work is being performed by operating organizations.

However, the City of Los Angeles, Bureau of Sanitation, has undertaken a pilot combustible rubbish collection project in the San Pedro area of Los Angeles. Mr. Warren A. Schneider, Director, has also suggested that it would be desirable to obtain further information concerning the most suitable method of transfer of refuse and best vehicle types and methods for obtaining refuse compaction for optimum pay-loads, transporting, and unloading rubbish. He also recommends further studies on the advantages of combined versus segregated refuse collections and the sanitary significance of once per week garbage collection in contrast to the twice per week collection now commonly rendered.

Other authorities, representing the City of Cincinnati and the City of Detroit, report a need for improved incinerator stack gas quality and other incineration criteria.

Universities

New York University has been reported to have started a research investigation on how to improve the efficiency of design for apartment and municipal

type incinerators.

The University of California at Los Angeles is currently continuing work on the basic design of incinerators for handling combustible refuse from household and industrial sources.

The University of Detroit has commenced a research project concerned with the identification and the instrumentation to measure discharge from municipal incinerators.

The Metallurgy Department at the Massachusetts Institute of Technology is conducting a comprehensive research program on how best to recover tin cans by smelting so as to separate the iron from tin. It is reported that over 1,000,000 tons of cans could be recovered per year out of the 3,000,000 or so of cans that go into food products consumed each year.

Michigan State University is continuing an investigation on aerobic decomposition (composting) of garbage.

At the University of Washington, Seattle, Washington, a study has been underway concerning the effect of the ratio of refuse to cover material on the settlement and compaction rates in land fills. A report by Mr. Walter L. Dunn, Assistant Professor, Department of Public Health and Preventative Medicine, University of Washington, states that after spreading and compacting refuse, it was possible to reduce the refuse volume by about 70 per cent and that one year after being placed the refuse was reduced approximately one-quarter in volume; that the most rapid rate of settlement of the land fill occurred within three weeks after placement; that the maximum temperature recorded within a 20 foot refuse fill was 101 degrees Fahrenheit at the center of the fill two weeks after placement.

Other Professional Refuse Engineering Activities

The American Gas Association is reported to be supporting a research project at Cleveland, Ohio, on smogless and odorless requirements for domestic incinerators. Several projects on incineration are also reported to be in progress at the Batelle Memorial Institute, Columbus, Ohio. The American Public Works Association has been active in refuse engineering development and currently is supporting two research projects on refuse collection and refuse disposal.

Separate American Society of Civil Engineering Committees are preparing manuals of practice concerning "Sanitary Land Fill" and "Municipal Incineration".

Summary of Conclusions

The evidence collected in this survey clearly indicates that refuse collection and disposal engineering practice is a relatively neglected area of engineering knowledge. The State Health Departments and other authorities have, with rare exception, reported that they have no knowledge of refuse engineering development projects taking place in their areas. In the United States there is some interest in research to improve incineration practice. In foreign lands, the use of compost type soil conditioners has resulted in composting research activity. The sanitary land fill (the most common and economical United States refuse disposal method) and other refuse engineering problems concerning collection and disposal, in general, requires further development.

The dollar value of United States refuse collection and disposal costs approaches in magnitude that involved for water supply, sewerage and storm drainage. There appears to be some increased awareness of the need for new engineering techniques to improve the art of refuse collection and disposal. A detailed description of known research and development projects has been briefly summarized. Other recommendations for such further investigations are also discussed.

The field of Refuse Engineering appears to be gradually developing on the American scene as an organized body of knowledge. Increased suburban growth has resulted in the need for higher standards of refuse collection and disposal. Additional research and development programs can aid in reducing the cost of solid wastes handling. There is also need for further specialized professional training and organization of the engineers involved in refuse handling systems.

Credit

This research report, which is one of a series of professional contributions by The Committee on Sanitary Engineering Research,

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	W. T. Ingram	Air Pollution
	M. A. Churchill	Stream Pollution
	F. G. Paloscay	Sewage
	C. H. Hull	Water
	H. A. Faber	Public Health
	R. Stone	Refuse
Chairman,	N. L. Nemerow	Industrial Wastes

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Journal of the

SANITARY ENGINEERING DIVISION

Proceedings of the American Society of Civil Engineers

SED RESEARCH REPORT NO. 15

On POSSIBLE CONTRIBUTIONS BY SANITARY ENGINEERS TO AIR POLLUTION RESEARCH

By The Sanitary Engineering Research Committee, Air Pollution Section

From the Data of: Collected Sources

Acknowledgement: The data presented herein represent the collective thinking of about 150 scientists engaged in air pollution research. They met in Cincinnati, December 18-20, 1956, at a Research Planning Seminar sponsored by the Public Health Service.

SYNOPSIS

Despite the need for contributions which the special training of the sanitary engineer can provide, few of them are presently engaged in air pollution research. Essential areas of investigation, both in the laboratory and in the field are described.

INTRODUCTION

Sanitary engineers by training and tradition are responsible for the evaluation and control of those factors of the environment which influence the health and welfare of man. Successful fulfillment of this responsibility is evidenced by a decrease in mortality from communicable diseases over the past 100 years. Sanitary engineers have performed this duty by proper treatment of public water supplies, treatment of sewage and industrial wastes, food and milk sanitation, stream sanitation, and improvement of the working

Note: There will be no discussion. Paper 1540 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. SA 1, February, 1958.

environment. Research carried out by sanitary engineers and workers in other disciplines have contributed greatly to the status of the public health today.

A new environmental sanitation problem has evolved during the past few decades. Increasing industrial activity accompanied by concentrations of population has created a serious situation by pollution of the atmosphere in many areas. Indices of the future point to a continually expanding technology and it is thus increasingly apparent that air pollution will be a critical factor for many years to come. It may even limit the growth of some metropolitan complexes. In order for any air pollution problem to exist, three conditions must occur simultaneously: a source of pollutants must be active; a susceptible population or other receptor must be present; and meteorological conditions must be such as to bring the two together. This, unfortunately, is happening to an ever-increasing extent.

Role of the Sanitary Engineer

Here is a situation which offers great opportunities for the sanitary engineer to continue his fight for better public health. His basic training has equipped him to respond to many of the needs in the control of air pollution. He can play an especially important part in preventing stream pollution which might result from some methods of controlling air pollution. His knowledge of the relationship between the two can help prevent the transferrence of pollution from one diluting medium to another. With sufficient incentive and initiative, the sanitary engineer can play a key role in research and the development of air pollution control programs.

As in the case of a stream receiving domestic or industrial materials, the air has a definite capacity for accepting and dispersing wastes in an innocuous manner. The capacity of a stream, under a given set of conditions, to recover from a pollutional load is fairly well defined but air pollution technology is some 50 years behind that of stream pollution. As yet, there is no way of determining the capacity of the atmosphere to accept and disperse air-borne wastes. Some of the concepts which were successfully used in stream pollution research can be applied to this newer problem.

Another example of the close relationship which exists between control of air pollution and other activities in which the sanitary engineer is actively engaged is in the control of air-borne industrial effluents. The general approach in this instance is the same one used for many liquid-waste problems. The most desirable step is to eliminate waste materials at the source by modification of the process. This might involve changes in the basic procedure of manufacturing or in the type of equipment used. Only where this approach is not feasible is it necessary to use other control methods. Where substitution or modification is not satisfactory, other devices or processes must be used to treat the waste discharge and make it less noxious. At an air pollution research seminar, called by the Public Health Service in December, 1956, it was concluded that "engineering research in the area of air pollution inherently includes economic consideration of control and elimination of contamination at the source. In this regard may be cited the fact that many otherwise well-defined processes consider only the product requirement and operational efficiency rather than the contaminants that may be discharged to the atmosphere as a result of the process." The sanitary engineer has faced and

successfully met this difficulty in connection with many situations involving the liquid waste of industry.

Many disciplines are needed to contribute to research in this field. Meteorologists, chemists, physicists, plant pathologists, physicians, and statisticians are only a few of the persons, in addition to engineers, who have major contributions to make.

Needed Research

Scientists and engineers in industry and state health departments are faced with a dilemma. On one hand is the demand from the public and by state legislatures to "do something" and on the other is the dearth of information about many phases of air pollution. At the present time, many facets of air pollution technology remain largely unexplored. The recent seminar, previously mentioned, was attended by about 150 scientists active in air pollution research in the United States. Committees were organized in the areas of agriculture, chemistry and instrumentation, engineering, medicine, and meteorology. The group compiled a list of necessary projects which included nearly 100 general areas of knowledge where research was urgently needed in addition to work presently in progress. This represents thousands of man-years of research and the expenditure of billions of dollars. Fortunately, much of the work will also find application in other fields.

The necessary research as defined by the appropriate committee is listed below in seven categories.

A. Atmospheric Processes

1. Investigation of self-purification processes in the atmosphere.
2. Fundamental research on atmospheric turbulence and diffusion.
3. Study of persistent atmospheric conditions which tend to produce severe pollution.
4. Development of pollution potential indices.
5. Investigation of the structure of the lower atmosphere in relation to basic diffusion processes, especially in urban area.
6. Research on pollution from remote resources.
7. Theoretical studies of diffusion from large area and volume sources.
8. Study of the influence of heat sources and sinks on air pollution patterns.
9. Development of scale model techniques for sampling atmospheric diffusion processes as related to area sources.
10. Development of methods for simulating terrain influences on air flow patterns.
11. Methods of interpreting climatological data for air pollution studies.
12. Investigation of the application of the method of multiple time series analyses, information theory, and stochastic procedures to the prediction of the probability distribution of the concentration of atmospheric pollution at a point.

B. Properties of Pollutants

1. Determination of properties, behavior, and methods of specification of aerosols.
2. Mechanism of smoke and fume formation including methods of modification.

3. Formation of aerosols during photolysis of polluted atmospheres.
4. Application of the particle size spectrometer to nucleation studies.
5. Relationship of the composition of aerosols to that of the feed material.
6. Changes accompanying the aging of particulate pollutants.
7. Development and evaluation of devices for the controlled production of aerosols.
8. Correlation of surface area of aerosols with other properties.
9. Effect of aerosol shape on light scattering.
10. Dynamics of movement of particles in large volumes.
11. Photolysis of organic compounds in oxygen.
12. Rates and mechanism of elementary reactions in the photolysis of nitrogen dioxide with hydrocarbons.
13. Photochemical reactions of effluents from known pollution sources.
14. Thermal reactions between ozone and unsaturated organic compounds.
15. Rate and mechanism of reactions occurring during incomplete combustion.
16. Nitrogen fixation in combustion equipment.
17. Photochemistry of organic and inorganic aerosols.
18. Heterogeneous reactions on surfaces.
19. Measurement of adsorption isotherms of pollutants.
20. Determination of the nature of the interaction of adsorbed species with the surface.
21. Studies of nucleation, atmospheric transmission, and adsorption of solar radiation.

C. Sampling and Analysis

1. Preparation of reliable gas and aerosol simulants.
2. Investigation of isokinetic sampling methods.
3. Fundamental studies of filtration mechanisms.
4. Further studies on electrostatic phenomenon.
5. Fundamental studies of adsorption and absorption of gases at low concentrations.
6. Behavior of particles approaching collecting surfaces.
7. Behavior of thermally conducting particles in a thermal gradient.
8. Development and evaluation of new type collectors for gases and aerosols.
9. Application to aerosol analysis of special techniques such as infrared reflectance, X-ray diffraction, chromatography, and electrophoresis.
10. Collection of specific gaseous contaminants by means such as ion exchange resins and molecular sieves.
11. Development and evaluation of adsorption techniques for the concentration of air pollutants.
12. Development and evaluation of methods and equipment for low temperature condensation of pollutants.
13. Development of specific economical analytical methods suited to special needs in very low concentrations such as differentiation of sulfur compounds.
14. Development of bio-assay methods such as enzymatic reactions and organism toxicity.
15. Development and evaluation of special nonspecific analytical techniques such as microbiological indicators for physiological effects.
16. Development of special analytical techniques for concentration involved in work with odorants.

17. Inter-laboratory comparison and statistical evaluation of analytical methods.

D. Instrumentation

1. Instantaneous quantitative gas spectrum analyzer.
2. Particle size analyzer for 0.3 microns to 0.01 microns.
3. Rapid mass distribution analyzer.
4. Simple fluoride gas-aerosol discriminator.
5. Simple stack effluent weight analyzer.
6. Light scattering analyzer for solids in gas streams.
7. Development of simple yet adequate meteorological instrumentation.

E. Process Evaluation

1. Compilation of characteristics and rates of effluent emissions.
2. Assessment of internal combustion engine emissions.
3. Determination of solid fuel process characteristics.
4. Appraisal of nitrogen oxide formation.
5. Relationship between transparent and opaque particulates.
6. General investigations of process modifications for pollution control.

F. Control Equipment Evaluation

1. Establishment of incinerator design criteria.
2. Evaluation of filter devices.
3. Evaluation of inertial separators.
4. Determination of electrostatic precipitator performance.
5. Development of high temperature filter media.
6. Evaluation of droplet-type scrubbers.
7. Exploratory studies of less common mechanisms for air cleaning.
8. Treatment and control of oxides of nitrogen emissions.
9. Conversion studies for gaseous emissions including catalytic and non-catalytic methods.

G. Survey Techniques

1. Design of a major air pollution investigation.
2. Acquisition of particle size data at ground level.
3. Comparison of hourly dustfalls.
4. Development and evaluation of tracer techniques using magnetic materials, microorganisms, and automatic counting methods.

Many of the above listed problems can be approached and solved readily by sanitary engineers with or without special training. Many others can be solved by sanitary engineers with special training in air pollution technology. At present few sanitary engineers are engaged in air pollution research despite the great need for contributions which their special training can provide. The research grants program of the Public Health Service and research grants from industry provide a special incentive for research in the field. It is unfortunate that more sanitary engineers have not taken advantage of these opportunities. It is essential, if sanitary engineers are to justify their continued existence as a special branch of engineering, that they prove they can meet the new problems of environmental control as well as solve the traditional ones.

Credit: This research report, which is one of a series of professional

contributions by the Committee on Sanitary Engineering Research,

	William T. Ingram	Air Pollution
	E. R. Hendrickson	
	Ralph Stone	Refuse
	R. H. Bogan	Sewage
	C. H. Hull	Water
	M. A. Churchill	Stream Pollution
	Harry A. Faber	Public Health
Chairman,	Nelson L. Nemerow	Industrial Wastes

has been prepared by the Air Pollution Section.

Paper 1541 February, 1958 SA 1

Journal of the
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Proceedings of the American Society of Civil Engineers

SED SPECIAL REPORT

On ENGINEERS JOINT COUNCIL POLICY STATEMENT ON AIR POLLUTION AND ITS CONTROL

By C. A. Bishop, Director—Chemical Process and Chemical Engineering Development, United States Steel Corporation, Pittsburgh, Pa.

From: EJC, Air Pollution Committee, Report approved September 13, 1957.

SYNOPSIS

Covers the background of the EJC committee and sets forth the principles of air pollution as well as certain general considerations, causes, and methods of control.

Before discussing the policy statement, the writer believes it would be of interest to discuss the background. In 1955, the Board of Engineers Joint Council approved the establishment of an exploratory group to study the implications of air pollution as related to public welfare and the responsibility of the engineering profession thereto, and report findings with appropriate recommendations to the Board of E.J.C.

Engineers Joint Council committees consist of an appointee from each constituent society. In the case of the Air Pollution Committee, we were most fortunate to have a broad cross-section of interests. Three members had experience as pollution control officials, one is a professor and the other five represented the industrial point of view. Mr. Seth G. Hess, Director and Chief Engineer of the Interstate Sanitation Commission, is the able representative of ASCE.

In addition to the committee members, Messrs. Lange and Wheelock of the

Note: There will be no discussion. Paper 1541 is part of the copyrighted Journal of the Sanitary Engineering Division, Proceedings of the American Society of Civil Engineers, Vol. 84, No. SA 1, February, 1958.

E.J.C. staff were helpful, and we were assisted by Mr. Fred Mallette, Secretary of ASME and well known in the air pollution control field. The personnel were all vitally interested and we had almost 100 per cent attendance at all Committee meetings.

The Committee agreed that the engineering profession had a responsibility in the solution of the air pollution problems and that a statement recognizing this fact should be prepared. One of the difficult problems was to define the expected audience. It was finally decided that the statement should be considered as a guide for those charged with the solution of the problem in their community or geographical region. It was also recognized that the statement would not be in any way a technical presentation since the engineering problems are reviewed by the various societies. The purpose was rather to focus the over-all problem with the views of the entire profession on the broad, non-technical policy matters and to define concisely the factors related thereto.

The Committee report was approved by the E.J.C. Board on September 13, 1957. We trust that it will prove helpful to the many persons who are working on air pollution control.

Now that we have seen the background for the statement, let us examine the principles delineated therein.

Principles

1. The common goal is to maintain a reasonable degree of purity of our air consistent with:

   a. The public health and welfare and public enjoyment thereof
   b. The continued industrial development of our country
   c. The protection of plant and animal life
   d. The protection of physical property and other resources.

2. Air pollution means the presence in the outdoor atmosphere of one or more contaminants, such as dust, fumes, gas, mist, odor, smoke, or vapor, in quantities, of characteristics, and of duration such as to be injurious to human, plant, or animal life or to property, or which unreasonably interfere with the comfortable enjoyment of life and property.
3. In the development of criteria for the control of air pollution, it must be recognized that although the atmosphere is a medium suitable for the disposal of waste products, true conservation requires that the public interest be protected against excessive and unsafe use of the atmosphere for this purpose.
4. Effective criteria are required to serve two purposes, namely, enforcement and protection of the public interest. The first of these can be most effectively accomplished at the points of emission, the second at the points of use. Sound criteria must give relative evaluation of these two measures.
5. In the development of standards, plans, rules or regulations, due consideration must be given to local conditions, such as topography, meteorology, industrial development, and area planning.
6. Emphasis should be placed upon education and voluntary cooperation by all persons and organizations who may contribute to air pollution or who are interested in its control. Encouragement should be given to

groups or associations of municipalities, industries, or other groups, who severally or jointly can be of help in planning its effective abatement.

7. Laws with appropriate penalties may be necessary, but their use should be reserved for cases where cooperation and voluntary action do not prevail.
8. During an emergency, such as may develop under adverse meteorological conditions, short-time curtailment of community and industrial activities which contribute to pollution may be necessary. Although such an emergency condition is seldom encountered, it is essential that duly constituted governmental authority anticipate such a problem, and be prepared to act through a prearranged procedure.
9. The objective of air pollution control legislation is to recognize the right to the use of the air and the responsibility to avoid its abuse. It is the duty of the engineer to contribute the knowledge of his profession in the preparation of legislation that will accomplish this objective.
10. Air pollution and its control involve many scientific problems that have not yet been solved. There is no simple or quick answer. Continued research in this field is vitally necessary. The engineering profession has the obligation of reaching the best engineering solutions to these problems.
11. It is the responsibility of the engineering profession to participate vigorously in the field of air pollution control.

General Considerations

Although vast in quantity, the air surrounding the earth is, in the present development of scientific knowledge, a limited resource. It consists essentially of oxygen and nitrogen in rather definite proportion, but also contains water vapor and rare gases in varying amounts. Its oxygen is essential to life and its nitrogen, through the action of plants, provides food. Its temperature and circulation keep us comfortable and its transparency makes possible the enjoyment of natural beauty, as well as safe aerial, land and marine transportation. It serves as a filtering and diffusing medium for sunlight and other forms of radiation, reducing them to levels acceptable to plant and animal life, and it is the medium by which water is returned to the land in the form of precipitation.

The air around us, the atmosphere, is continuously exposed to both natural and artificial contamination. Every individual contributes to natural contamination by his metabolism and to artificial contamination by his activities. The activities of industry also discharge large quantities of polluting materials into the atmosphere daily. Fortunately, under most conditions, these pollutants are rapidly dispersed and diluted so that the effect is unnoticeable. It must, however, be recognized that meteorological conditions may and sometimes do exist which prevent the rapid dispersion and dilution of the polluting materials. Such conditions may result in serious air pollution and may create a public nuisance, an economic barrier to further industrial expansion and a serious health hazard.

The unprecedented expansion of industries and increase in population has caused this problem to develop before basic research essential to an adequate understanding of the many factors involved was possible. Much remains

unknown relative to the direct effect of the type and concentration of contaminants or the actual mechanism by which harmful results are produced in the human body. In certain types and concentrations of pollution, relative short times of exposure have proven fatal. The effects of long times of exposure to other types and concentrations are not as yet known. There is urgent need for basic research to develop more adequate knowledge in this area.

As the air is a limited resource, its maximum use in the most efficient and economical manner is vitally important. To ignore the air's capacity to stabilize waste products or to overtax this capacity constitutes waste of a primary element in our economy, health, and welfare. The atmosphere is a natural resource that must be shared by all. Control of its pollution is a community problem. The individual must be subject to reasonable limitations on its use as may be required in the public interest.

The sources of natural pollution are many. As a result of natural phenomena, the atmosphere contains gases from the decomposition of animal and vegetable matter; products of volcanic and weathering action and of meteoric disintegration; spores; pollens and bacteria; and, in some sections, other vapors, gases and particulates. Generally these pollutants are absorbed or stabilized by the atmosphere.

Current technical data support the idea that the contaminants which cause serious pollution are those that result from man's own activity. The atmosphere is used as a disposal medium for man-made waste processes. When mixed together and subjected to sunlight and other natural phenomena, these products cause complicated reactions producing a multiplicity of secondary effects. The increase in industrial activity and in the concentration of our population has resulted in an increase in both the quantity and the concentration of such waste products in the atmosphere, a condition which often results in serious air pollution in urban areas.

In rural areas, on the other hand, pollution may result from excessive quantities of dust and vapors, both toxic and non-toxic, odors and pollen. Considerable progress has been made in the development of methods for controlling the sources of such pollution through scientific soil management and other methods of control.

While air movements disperse and dilute contaminating materials, meteorological conditions can be such that these materials may be transported with relatively little dispersion or dilution even over very great distances. Pollens, dusts and other contaminants from forest fires, wind action, volcanoes, and nuclear tests have been found in the atmosphere far from their sources. A change in meteorological conditions will cause the contaminants to settle out directly or fall to the earth with the rain or snow. As a consequence, air pollution is a world wide problem.

To prevent detrimental concentrations of atmospheric pollutants, one must recognize what constitutes an offensive discharge and determine the allowable concentration of these constituents. Methods must then be found to keep the character and the amount of discharge under control. Most often the pollutant causing aggravation evolves from an operation in which some branch of the engineering profession is concerned. Effective and adequate control must therefore be started at the source of the pollution by engineering personnel.

Legislation at various levels of Government may be desirable. Effective control can result only under legislation which is both fair and equitable, and at the same time, provides for adequate penalties for violations. It must be carefully prepared and be flexible, yet specific, in order to be adjustable to the needs of all areas.

Responsible administration should start at the lowest Government level capable of dealing with this technical problem. The public must be fully informed and accept the fact that each individual is both a contributor and a victim.

Causes of Pollution

Contaminating substances, both gaseous and particulate, are always present in the atmosphere. The quantity, concentrations and characteristics of the contaminating substances found in the air at a particular time and place determine the degree of air pollution.

Air pollution from natural causes is usually of minor concern. However, volcanic gases and ashes have, on occasion, laid waste whole countrysides, and spores and pollen regularly cause distress to large numbers of susceptible people, and fogs interfere greatly with our comings and goings. These are the results of natural phenomena and at present it is difficult to mitigate these forms of air pollution. It is, therefore, the pollution resulting from man's own activities upon which the efforts of engineers presently can be most fruitfully exerted. Some idea of the complexity of the problem to be solved may be indicated by a brief listing of the major activities of people in our existing society and their contribution to the air pollution problem.

1. Agricultural activities—dusts from land cultivation, fertilization and crop handling; odors, of both vegetable and animal origin; pollens and insecticides.
2. Commercial activities—products of combustion from fuels used for heating and cooking and from garbage and refuse disposal by open burning or incineration.
3. Construction activities—chiefly dust.
4. Domestic activities—discharges similar to those from commercial activities differing only because of size and number.
5. Industrial and manufacturing operations—products of combustion of fuels, also dusts, gases and odors arising from materials being processed.
6. Transportation—products of combustion from land, marine and air vehicles, road dust and tire dust.
7. Waste disposal—products of combustion from the burning of waste materials, either in the open or by incineration, and dusts, gases and odors from the handling of waste materials or from areas where they have been dumped.

Any of these activities can, and on occasion do, cause annoyance to people. Such annoyances can range from the effect of an improperly adjusted domestic heating furnace, which discharges soot that soils the immediate neighborhood, to an open burning dump spreading a pall of smoke, noxious gases, and odors over a considerable area. They also include many types of commercial and industrial gases, dusts, or odors which, depending upon their quantity and characteristics, may be annoying or damaging to property.

There is another type of air pollution, which has come into prominence lately. It is a general pollution of the atmosphere above urban and metropolitan areas, which cannot be charged to a single individual or enterprise, but is a result of our complex society. The exhaust from a single automobile in

proper mechanical condition is hardly observable. Yet the exhaust from two solid lines of such cars passing through a tunnel becomes so lethal that an elaborate ventilating system is required. Conditions in a narrow street, lined with tall buildings, are scarcely better unless our natural ventilating system, the wind, dissipates the fumes.

Thus, above many of our major metropolitan areas, because of the congestion of population, density of traffic, and magnitude of industrial operations, an immense and ever increasing amount of contaminants is poured forth daily into the atmosphere. There they react, not only with each other, but also with the water vapor and ozone naturally present. The net result is commonly referred to as smog.

The seriousness of the condition depends on two major factors. One, is a function of the total amount and characteristic composition of material being discharged into the atmosphere. The other is a function of the meteorology and topography of the region.

The effect of meteorology is pronounced. On one day the air may be clear and visibility unlimited, on the next we can scarcely see the length of a city block. Sustained winds, atmospheric turbulence, and the lack of temperature inversions all help to dissipate the man-made fog above our cities. On the other hand, windless days, a "heavy" atmosphere, and nightly temperature inversions all tend to concentrate, rather than disperse, the pollutants. If these unfavorable atmospheric conditions persist for several days, the concentration of pollutants continues to rise.

Unfavorable topography likewise induces an increase in concentration levels, by confining the polluted atmosphere and preventing its lateral movement. Valleys, or even a range of hills, are the usual unfavorable topographic features.

Methods of Control

Control of industrial and domestic pollution may be attempted in one or some combination of three ways: (1) by dilution, (2) by abolition, or (3) by treatment.

Control by dilution is an age-old method. It has been used, knowingly or unknowingly, from the beginning of time and it will continue to be used as a means of final disposal for wastes. The method has many advantages and much capacity for disposing of contaminants effectively. It fails miserably, however, when its limitations are not strictly respected. These limitations, of course, are as capricious as the winds themselves. Complete reliance on the dilution method may, under adverse weather conditions, result in nuisance or more serious conditions. By taking advantage of favorable factors, such as isolation from urban population and releases of contaminants at reasonable high elevations, however, disposal by dilution can be satisfactory.

Another method of air pollution control is abolition of the sources of trouble. No doubt this is the perfect solution, but unfortunately, its application is often restricted because of cost of impracticability. Where abolition is practical it should be used in preference to other methods. For example, open fires, with their poor combustion possibilities and attendant hazards, should not be tolerated in most instances.

The third method of air pollution control is by treatment of the wastes to reduce their potency and other unfavorable characteristics before they are

discharged into the atmosphere. This approach, in its simplest terms, is an adjunct to the dilution method; it can make the dilution method work to advantage. Many corrective methods are now available to the engineer to treat potential air pollutants. Some of the more common ones are: (1) superior combustion chambers, (2) scrubbing facilities, (3) settling chambers, (4) filters, (5) mechanical separators, (6) electrostatic precipitators, and (7) counteractants. Where applicable, each of these devices has provided a significant contribution to air pollution reduction.

Abatement of air pollution may also be accomplished by centralization of disposal functions as opposed to individual disposal. An example of this method of abatement is the collection of rubbish by a central agency from homes, apartments and commercial places for complete and adequate disposal by incineration or by sanitary land-fill method. The elimination of innumerable and inefficient individually owned incinerators by this plan, materially reduces the air pollution potential.

Many other practices and programs that were designed with other objectives in mind have helped reduce air pollution. For example, the paving or surfacing of streets and parking lots prevents the development of dust pollutions from these areas on windy days.

Thus, in most circumstances air pollution is amenable to control. Some pollution problems, however, have resisted solution and need the application of research if progress is to continue. In seeking an approach to air pollution control it is not enough to identify substances from the polluted air and then seek methods of reducing the quantities of these materials. Some of them may be only the innocuous end products of reactions of unstable substances that may be the real cause of the trouble. A knowledge of the chemical components of pollutants while airborne, of the catalytic substances present, of the reactions which occur and of the shifting equilibria which are reached under varying conditions will be necessary in identifying offensive materials and in developing methods for counteracting them. To meet this and many other challenges in this field, research is required. The recovery of sulfur from stack gases and the design and development of a satisfactory home and apartment incinerator which will minimize air pollution, are typical of the problems which need solution through study.

Indiscriminate discharge into the atmosphere of waste materials which may become obnoxious or toxic, simply because no other method of disposal is known, should no longer be condoned. Scientific study and research for the satisfactory control of such discharges should precede the event rather than follow it.

The cost of air pollution abatement should be commensurate with the benefits accruing to the people. Fortunately this condition normally prevails and, because it does, air pollution control is not beyond our reach. The present thinking on pollution control leans heavily on provisions for the reduction and treatment of wastes prior to the beginning of operations at new plants. By this means, pollution can be controlled before it has a chance to do any damage.

The Engineer's Function

Engineering involves directing the forces of nature and the activities of man to his own use, convenience and welfare. In view of air pollution's causes

and effects, and the technical nature of its control, the engineering profession is qualified and is duty bound to contribute substantially to the control of air pollution.

Engineers are involved, through research, development, design, construction, installation, operation and maintenance, in activities that bring into being man-made sources of air pollution. Engineers have already made substantial contributions to the solution of air pollution problems by application of technical knowledge. Many of these contributions have resulted from efforts to utilize fuels and raw materials more effectively, while others have come from efforts specifically directed to minimizing air pollution nuisances and hazards.

Other professional disciplines are contributing to effective air pollution control in many fields; including agriculture, biology, government service, law, medicine, meteorology, politics, public health, science, and soil conservation.

The engineering profession is prepared to discharge its responsibilities in the physical control of air pollution by full participation with other professional disciplines, in establishing and effecting sound policies of control.

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WATER QUALITY IN THE MISSOURI RIVER[1]

Glen J. Hopkins,[2] and Joe K. Neel[3]
(Proc. Paper 1542)

Quality of water in the Missouri River is subject to the varying influences of a large number of pollutional discharges and, during recent years, has been affected by main stem impoundments involved in the Corps of Engineers Developmental Program. The office with which we have been associated for the past several years has been fortunate in having the opportunity to cooperate in studies dealing with both aspects. Participation in pollutional studies in critical reaches of the main stem began in 1949 when an agreement for cooperative investigations of the Missouri River from Yankton, South Dakota, to St. Louis, Missouri, was entered into by the U.S. Public Health Service and State Health Departments of Iowa, Kansas, Missouri, Nebraska, and South Dakota. These investigations led to development of the cooperative State-Federal report, "Lower Missouri River Basin - Water Pollution Investigation."(1) We have developed water pollution reports on the Upper and Central Missouri River Basins,(2,3) the region of the Missouri River incorporated in the Missouri - Souris Development Area(4) and the report "A Comprehensive Program for Control of Water Pollution - Missouri Drainage Basin."(5)

Our association with water quality aspects of the developmental program began in 1952 when we initiated a cooperative study of reservoir influences with the Missouri River Division, Corps of Engineers, and State Health Departments in Iowa, Nebraska, North and South Dakota. This study developed from concern over the river's potential as a plankton producer following clarification expected from the reservoir system. Although algal problems had never occurred in the muddy river, state health authorities and waterworks officials were fearful that reduced turbidities could promote

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1. Presented to the Sanitary Engineering Conference, Kansas City Section, American Society of Civil Engineers, Kansas City, Missouri, Nov. 19-20, 1956.
2. Sanitary Engineer Director, Public Health Service, U. S. Department of Health, Education & Welfare, Region VI, Kansas City, Missouri.
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serious algal growths. The State Health Departments of the Lower Basin, through a recommendation of the Engineering Section, Missouri Basin Health Council, February 27, 1952, requested the Public Health Service to assume over-all responsibility for a comprehensive study. The Public Health Service outlined an investigational program and elicited cooperation of the Corps of Engineers. The Corps of Engineers agreed to furnish major financial support, and the State Health Departments agreed to cooperate as possible and consistent with their resources. The Public Health Service assumed direction of the study, which began in August, 1952, and has continued to date.

Reservoir Influences upon Water Quality

The initial phases of the study were concerned with determination of water quality relationships before impoundment; later the effects of various impoundments were studied.[6,7,8] Ft. Peck Reservoir, in operation at the beginning of the investigation, was relied upon to maintain navigational flows in late summer and autumn. These releases had influences that were evident early in the investigation; and, because of them, it was not possible to secure data representative of the river in its natural condition. It should be understood that material presented here is indicative of changes wrought by centrally located reservoirs upon a river whose upper reaches were already under the influence of a large impoundment.

Description

The river reach covered by our investigations extends from Williston, North Dakota, to Omaha, Nebraska, a distance of 1,012.2 river miles. Major discharge into this reach originates in Ft. Peck Reservoir and the Yellowstone River. The Yellowstone and Little Missouri Rivers drain extensive badlands areas and contribute heavy silt loads to the Missouri.

Other tributaries from the west, the Knife, Heart, Cannonball, Grand, White, and other rivers, have considerably less influence; and tributaries entering from the east are few and of little consequence above the mouth of the James River. Heavy discharges from the Big and Little Sioux Rivers markedly affect the Missouri as far as Omaha, Nebraska.

Main stem reservoirs now completed are Ft. Peck which was placed in operation many years before the start of our studies. Closure of other dams occurred as follows: Ft. Randall, August, 1952; Garrison, December, 1953; and Gavins Point, August, 1955.

Turbidity

Despite its traditional muddy appearance, the Missouri did not carry a particularly heavy sediment load in terms of dry weight per volume. The apparently anomalous situation of high turbidity and relatively low sediment load was due to the predominance of small flattened clay particles that effectively reflected light without providing much weight.

Before significant flow regulation was furnished by impoundments below Ft. Peck, turbidity relationships were practically identical in all river reaches sampled, being lowest during periods of ice cover and highest during heavy flows in spring and early summer. Uniform discharges promoted by Ft. Peck releases in summer and early fall were characterized by

uniform midrange turbidity. Greatest turbidity contributions came from surface runoff. Bank erosion produced lesser amounts, and bed scour was an insignificant source.

Reservoir effects upon turbidity may be discerned by reference to Table 1, which shows pre- and post-impoundment concentrations at two locations below each major reservoir (Garrison and Ft. Randall).

Reduced turbidity resulting from reservoir impoundment was evident all the way downstream to the Mississippi River. The extent of this reduction is evident from annual average turbidities covering the last 16 years of record at selected water plants in lower reaches (Table 2).

Hardness and Alkalinity

Reservoirs have both increased and decreased river hardness and alkalinity concentration during the period of our study. Increases have stemmed from soil leaching associated with initial filling, and from thermal stratification; whereas decreases have resulted from photosynthetic carbonate precipitation during intervals of rather uniform reservoir elevation, and from dilution afforded by storage of peak seasonal discharges having lowest mineral content. Annual average total alkalinity and total hardness at selected locations, 1953-1955, appear in Table 3. It is evident from this table that Ft. Randall Reservoir has consistently reduced hardness and alkalinity on an annual basis. Garrison Reservoir added to these elements in its inflowing water in 1955, and thereby contributed to their increased concentration at most downstream stations. 1955 was a year of steadily increasing water level in Garrison Reservoir.

Hardness and alkalinity reductions in Ft. Randall Reservoir have resulted in annual bottom deposits of contributory minerals. In 1953, and 1954, it is estimated that 471,000,000 pounds of alkalinity and 530,000,000 pounds of hardness were precipitated from impounded water. In 1955, alkalinity and hardness removal amounted to about 120,000,000 pounds and 270,000,000 pounds, respectively. Conversely, through leaching, Garrison Reservoir picked up about 206,000,000 pounds of alkalinity and 103,000,000 pounds of hardness from its floor in 1955.

Carbonate deposits upon reservoir floors may lead to hardness and alkalinity increases in discharged waters if density layers form and endure for sufficient time to permit significant production of carbonic acid to react with carbonate in deeper waters. Such increases have appeared during the limited periods of thermal stratification that have occurred in the still relatively shallow reservoirs.

Plankton Algae

The Missouri River had very infrequently imposed biological problems upon water treatment at any municipal plant. A plankton reconnaissance made by the U.S. Public Health Service in 1950(9) and a study of the lower Missouri completed in 1945(10) both demonstrated a very low concentration of taste and odor producing organisms in the main stem, and led to the assumption that development of such algae had been largely suppressed by excessive turbidity.

Early phases of our investigation showed low plankton production in the main stem, and indicated that the algal population was composed of those forms of tributary origin that were able to survive conditions in the big river. Tributaries differed considerably in plankton populations, but the screening their discharges were subjected to resulted in general uniformity of phytoplankton over the entire sampled reach of the Missouri. Turbidity was substantially reduced when significant impoundment was made in Ft. Randall Reservoir in late June, 1953. In August, this reservoir developed a high plankton concentration which increased its numbers when discharged to the river below, and occasioned taste and odor problems in water supplies withdrawn at Yankton. Concentration at that point was equivalent to an algal thread 5 microns in diameter and 4.29 miles in length in each gallon of water. The Yankton water plant eventually controlled the situation with large dosages of chlorine and activated carbon. The problem was the first of that nature in the experience of the plant operators. The Public Health Service furnished advanced notice of the impending problem, but initial steps taken at the water plant were unrealistic in view of actual concentrations involved. Algal densities in the critical range also occurred at Yankton in spring and summer of 1954 and 1955. The operators instituted more adequate control measures following advance notice of these subsequent developments, and were generally able to maintain a palatable finished water.

Garrison Reservoir produced no algal crops great enough to impair water quality during its first year of impoundment, 1954. However, in 1955 its effects in this regard occasioned water treatment modifications for control of tastes and odors at Mandan and Bismarck, North Dakota, in April and May. Advance notice of impending algal development was helpful to plant operators; but their precautionary measures were somewhat unrealistic and they did not survive the algal bloom without complaints from consumers. Special procedures for control of taste and odor were also required upon several occasions at Chamberlain, South Dakota. This water intake is either in, or just above, the head waters of Ft. Randall Reservoir, depending upon water elevation, and thus has been affected by algal blooms originating in both Garrison and Ft. Randall Reservoirs.

The effects of reservoirs upon annual average plankton concentration at selected stations are shown in Table 4. In most instances increased densities at river stations represented survival of reservoir growths, but upon several occasions a local river development was responsible. Concentration at Yankton, for example, was often elevated by plankters contributed from the Niobrara River.

Development of phytoplankton, although causing water treatment difficulties upon reaching certain levels, was in some respects of benefit to water quality in the Central Missouri River. Its photosynthetic activity played a major role in hardness and alkalinity reductions attributable to reservoir storage. The normal pH range of the Missouri River is above 8.0. At that level no free carbon dioxide can exist, and algae are faced with the problem of extracting 00_2 from either carbonate or bicarbonate. They are unable to deal with carbonate, but very readily extract 00_2 from calcium and magnesium bicarbonate, leaving carbonate and water as waste products. As the solubility level is exceeded, carbonate settles to the reservoir floor, reducing hardness and alkalinity in proportion to the quantity of calcium and carbonate ions withdrawn from solution. Precipitation of carbonate in this manner has been largely responsible for deposits that have occurred in Ft.

Randall Reservoir. So far, phytoplankters have been unable to offset increased quantities of bicarbonate brought into solution from the floor of Garrison Reservoir.

With regard to tastes and odors, it is believed by some that ray fungi (Actinomycetes) are the causative agents of all naturally occurring unpalatable water flavors, either by their free growth in turbid situations or their parasitism of algal cells. In the Missouri River all post-impoundment taste and odor problems that have come to our attention have been associated with dense algal growths.

We are omitting reference to other reservoir modifications of water quality in order to devote some time to the role of pollution. But, before leaving the subject of reservoirs, we would like to mention that turbidity and hardness reductions have resulted in substantial savings in water treatment chemicals at those plants where continuity of operations has permitted valid comparison of pre- and post-reservoir records.

Pollutional Influences

The Missouri River receives its heaviest pollution in the stretch from Sioux City, Iowa, to just below Kansas City, Missouri. Into this reach are poured, in a raw state, wastes from the largest concentrations of people along the river, the unwanted residues from large packing houses and other agricultural processing industries, and processing wastes from oil refineries, chemical industries, and steel plants. The meat packing industry, with large establishments at Sioux City, Omaha, St. Joseph, and the Kansas Citys, contributes the largest share of organic wastes.

In 1952, Sioux City, Iowa, including industries, discharged a waste load equivalent in oxygen consuming power to that from 796,000 people. Combined industrial and municipal wastes from other cities in rounded population equivalents were as follows: Council Bluffs, Iowa, 47,000; Omaha, Nebraska, 1,554,000; St. Joseph, Missouri, 558,000; Kansas City, Kansas, 840,000; Kansas City, Missouri, 2,120,000; Kansas City, Missouri, 181,000. The Kansas Citys discharge to the main stem and to the Blue and Kansas Rivers shortly above their mouths.

Discharges are increasing with industrial and population growth. Programs leading to abatement and treatment are in active planning; and the next few years should see substantial progress in reduction of pollution.

Effects of this pollutional load upon water quality are many and varied. Great numbers of coliform-type bacteria are contributed by domestic and packing house wastes. Generally, their densities rise shortly below each major community, then gradually decline until elevated again by discharges from the next large downstream community. In 1950, median summer coliform MPN per 100 ml was 93,000 at Sioux City; 46,000 at the Omaha water intake; 180,000 at Nebraska City; 33,000 at the St. Joseph water intake; 68,000 at Leavenworth, Kansas; 58,000 at the Kansas City, Kansas, water intake; 150,000 below Kansas City, Missouri; 120,000 at Lexington, Missouri; 43,000 at Jefferson City; and 9,300 at the St. Louis Co. water plant intake. Coliforms contributed at St. Joseph appeared to better survive the trip to the Kansas City, Kansas, water intake during higher discharges, which reduce the time of travel and more than compensate for greater dilution by getting the bacteria to the downstream location at a higher point on their dieaway curve.

industrial and domestic wastes and sizable amounts of hardness that contribute to fluctuations in raw water content and often overshadow or completely negate reductions occurring in upstream reservoirs. They also contribute to turbidity and add many organic solids that complicate water treatment and bring accumulations of undesirable materials into settling basins.

Oil refineries have frequently released compounds that have attributed a bad taste to water supplies withdrawn over long reaches of the river. Breaks in gasoline and other pipelines crossing the river have resulted in tastes and odors of long duration, as effects of such compounds linger for days following their entry into a water plant. Objectionable flavors occurring at Boonville and Jefferson City, Missouri, in the winter of 1955-56 are generally associated with waste discharges from oil refineries in the Kansas City area.

Other undesirable aspects of pollution, as increases in biochemical oxygen demand, reductions in dissolved oxygen, compounds toxic to aquatic life, and nutrient enrichment for objectionable algal growths, stem from waste discharges to the lower Missouri. So far, algal stimulation inherent in many discharged compounds has not occurred, as turbidity, even with reservoir attenuation, has not declined sufficiently to permit active algal growth.

Discharge levels in the lower river are directly involved in the degree of various pollutional effects. Upon joint recommendation of the U. S. Public Health Service and State Health Departments and with the concurrence of other interested State and Federal agencies, the Corps of Engineers maintains winter discharges in the range considered essential for upstream waste dilution. However, reservoir releases may not adequately contend with flow restrictions due to ice formation and jamming, since it is rarely possible to time increased releases to coincide with periods of ice formation, particularly as several days are required for reservoir discharges to reach the Kansas City area.

In the winter of 1955-56, unsavory flavors and accumulations of floating organic materials appeared in water plants downstream from the Kansas City area shortly after flow was reduced by ice formation. Solids were of the sort associated with meat and poultry packing industries, and their accumulations in water plant settling basins were extremely unsightly. Very low discharge (slightly above 4,000 cfs) caused greater concentration of such materials; but their dense accumulations also resulted from isolated concentrations caught among floating ice floes and increased velocity of tributary inflow following stage decline in the Missouri. For instance, very low flows prevailed in the Kansas River, its discharge was further allowed by a stage of comparable elevation in the Missouri, and a large accumulation of packing house and municipal wastes built up shortly above its mouth. When stage dropped with ice formation in the Missouri, velocity of flow increased in the Kansas, and the waste accumulations moved out.

The relationship of discharge to concentration of pollutants in the main stem in indicated by the quantity of chlorine required to reach the break point at various discharge levels at Atchison, Kansas (Figure 2). Chlorine data used in plotting this figure were supplied by Mr. A. E. Weatherford, Plant Operator, the Atchison City Water Works, Inc. Water in the lower main stem is largely supplied by reservoir releases, and high stages during summer months chiefly represent increased reservoir discharges. Lacking, therefore, is the usual direct relationship between chlorine demand and discharge when flow augmentation results from increased land runoff. Chlorine

demand under these circumstances of controlled flow in the lower river is largely a function of wastes concentration, which, of course, becomes greater as flow decreases.

It is thus evident that sudden reduced discharges resulting from ice interference play a critical role in water quality during winter months, and may be largely instrumental in increased frequency of taste and odor problems during that period. It is also evident that pollution adversely affects water quality for municipal use during the non-navigation season.

Experiences during the winter of 1955-56 led to a joint request by the Public Health Service and State Health Departments that the Corps of Engineers increase minimum winter flows by 2,000 cfs. This request, based on an interim basis pending progress in pollution abatement, was granted. It must be borne in mind, however, that additional flow allotments will not be able to keep pace with steadily growing pollution; and that the only solution to the problem lies in the provision of adequate abatement.

We are happy to report some progress in this regard. Active planning for pollution abatement above the Kansas River is now under way. Firm assurance has been given that treatment works will be under contract by January 1, 1959, at Yankton and Vermillion, South Dakota, and Sioux City, Iowa. Omaha, Nebraska, proceeding on a program for completion of detailed planning and purchase of a plant site by January 1, 1959, has by public referendum endorsed service charges to defray improvement costs. St. Joseph, Missouri, has, by resolution of the City Council, committed itself to construction contracts in 1959 and to arrange financing in 1957. Planning is under way at Atchison, Kansas, and has been completed at Leavenworth. Kansas City, Kansas, has completed preliminary planning and posted $3.7 million to initiate work on interceptor sewers. These are encouraging developments. As soon as Kansas City, Missouri, begins the development of an effective pollution abatement program, ultimate cleanup of the Missouri River will become, for the first time, a definite possibility.

BIBLIOGRAPHY

1. Lower Missouri River Basin - Water Pollution Investigation, Water Pollution Series No. 47, U. S. Public Health Service, October, 1952.

2. Upper Missouri River Drainage Basin - A Cooperative State-Federal Report on Water Pollution, Water Pollution Series No. 25, U. S. Public Health Service, May, 1952.

3. Central Missouri River Drainage Basin - A Cooperative State-Federal Report on Water Pollution, Water Pollution Series No. 24, U. S. Public Health Service, June, 1952.

4. Missouri-Souris Development Area - Water Pollution Investigation, Water Pollution Series No. 32, U. S. Public Health Service, November, 1951.

5. A Comprehensive Program for Control of Water Pollution, Missouri Drainage Basin, U. S. Public Health Service, Water Pollution Series No. 56, July, 1953.

6. Central Missouri River Water Quality Investigation, August, 1952 - December, 1953, U. S. Public Health Service, April, 1954.

7. Central Missouri River Water Quality Investigation, 1954. U. S. Public Health Service, August, 1955.

8. Central Missouri River Water Quality Investigation, 1955. U. S. Public Health Service, August, 1956.

9. Damann, K. E., 1951. Missouri River Basin Plankton Study, 1950. U. S. Public Health Service.

10. Berner, L. M., 1951. Limnology of the Lower Missouri River, Ecology 32:1-12.

Table 1. Average Annual Turbidities (ppm) at Selected Localities

	1953	1954	1955	
Bismarck, N. Dak.	957	89	77	Below Garrison Reservoir
Pierre, S. Dak.	1,046	260	299	
Yankton, S. Dak.	419	124	93	Below Ft. Randall Reservoir
Omaha, Nebr.	827	545	338	

Table 2. Average Annual Turbidities ppm. Water Plant Records

	Leavenworth Kansas	Kansas City Kansas	Boonville Missouri	St. Louis Co., Mo.
1940	2,810	2,110		1,900
1941	3,196	2,899		2,300
1942	3,237	2,192	6,300	1,700
1943	2,161	1,668	1,800	1,300
1944	2,380	2,052	1,900	1,900
1945	1,073	2,085	1,800	1,500
1946	1,048	2,330	2,200	2,200
1947	1,793	1,450	1,100	1,100
1948	1,994	1,849	1,600	1,700
1949	1,551	1,450	1,500	1,500
1950	1,861	1,870	1,800	1,700
1951	2,060	1,890	1,300	1,400
1952	1,400	1,308	1,200	1,100
1953[a]	775	803	800	800
1954[b]	770	810	1,000	800
1955[b]	534	570	1,000	600

[a] Ft. Randall Impoundment - August, 1952
[b] Garrison Impoundment - December, 1953

Table 3. Average Total Alkalinity and Hardness (ppm)

	Alkalinity			Hardness		
	1953	1954	1955	1953	1954	1955
Above Garrison Reservoir		169[a]	150		246[a]	221
Below Garrison Dam		158[a]	160		216[a]	235
Bismarck#	160	158	166	224	211	229
Pierre				268	231	246
Chamberlain (above Ft. Randall Reservoir)	157	154	158	271	247	248
Below Ft. Randall Dam	147	144	153	259	240	236
Yankton	150	145	150	264	238	232
Omaha#		172	170	261	241	247

[a] July - December Records
Water Plant Records

Table 4. Average Annual Plankton Concentration, No. per ml.

	1952	1953	1954	1955
Above Garrison Reservoir			79[b]	62
Below Garrison Dam			192[b]	207
Mandan, N. D.			174[b]	175
Pierre, S. D.	33[a]	63	144	242
Chamberlain, S. D.	44[a]	67	185	295
Below Ft. Randall Dam	49[a]	119	430	277
Yankton, S. D.	119[a]	312	426	304
Omaha, Nebr.	116[a]	138	264	259

[a] August - December Records
[b] July - December Records

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THE EFFECTS OF AIR POLLUTION ON AIRPORT VISIBILITY[a]

William T. Ingram,[1] M. ASCE and Louis C. McCabe[2]
(Proc. Paper 1543)

SYNOPSIS

The New York metropolitan area has three large airports—LaGuardia, Idlewild, and Newark—that combined handle more air traffic per day than any other metropolitan airport system in the United States.

The total traffic at these ports in the year 1955 amounted to 452,088. LaGuardia, with 223,005, handles nearly as much traffic as Newark (105,644) and Idlewild (123,439) combined (229,083).

Safety standards at airports require that aircraft be operated on instrument control under certain visibility conditions. It is therefore a matter of serious concern if poor visibility and low ceilings are prolonged over the periods when adverse weather conditions limit airport use, or if visibility over airports is critical or within instrument control limits when elsewhere there is no fog, haze or smoke.

Atmospheric contaminants include the combustion products of heating fuels, effluents from chemical and metallurgical processes, refineries, disposal plants, burning dumps, incinerators, and motor transportation. The contaminants from these processes exist in the atmosphere as gases, vapors, dusts and fumes. Gases or vapors include the permanent gases as well as the compounds that boil below 300° C, which when present in low concentrations exist only as vapor.

Current information and records have been studied in order to orient the approaches that might be made, and recommendations for further research investigation have been developed as a result of the present study.

There is no justification for singling out any one industry or municipal source of smoke emission for special note as the basic cause of haze or smog

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over the New York metropolitan area. It is obvious that localized sources (1-5 miles radius of field), even though contributing, are only adding to a general accumulation of haze-producing substances. The area to be considered in assessing the total haze accumulation must extend from Nassau County on the east to a general line west of urbanized and industrialized developments in New Jersey.

General Information

The New York metropolitan area has three large airports—LaGuardia, Idlewild, and Newark—that combined handle more air traffic per day than any other metropolitan airport system in the United States.

The total traffic at these ports in the year 1955 amounted to 452,088. LaGuardia, with 223,005, handles nearly as much traffic as Newark (105,644) and Idlewild (123,439) combined (229,083).

Safety standards at airports require that aircraft be operated on instrument control under certain visibility conditions. Limits are established below which a field is closed entirely. It is therefore a matter of serious concern if poor visibility and low ceilings are prolonged over the periods when adverse weather conditions limit airport use, or if visibility over airports is critical or within instrument control limits when elsewhere there is no fog, haze or smoke.

Either condition produces airport congestion, delays in flights, losses in operating time, and hence increases in operating cost. Hazard and nuisance increase since aircraft must descend to a lower level before establishing ground contact prior to landing. Both aircraft occupants and community residents are subject to the dangers and annoyance thus occurring. Flight takeoffs are frequently impeded by limited ground visibility thus causing an increase of taxi time, unnecessary operation of aircraft engines at idling speed, wasted fuel, and increased costs to airlines.

Thousands of dollars are lost each year because of limited airport visibility. C.A.A. records(1) of weather at Newark for a period of five years (1934-1938) show the causes of visibility of 0-1 mile during winds of 0-5 mph. Fog (67.96%) and smoke (31.26%) preponderantly accounted for the average low visibility, amounting to 389 hours per year, due to fog, smoke, rain, dust and snow.

It is obvious to aircraft crews and passengers that air visibility is obstructed by atmospheric pollution over the New York metropolitan area. On clear days with unlimited visibility elsewhere a pall of haze obscures the metropolitan area as an approach is made.

Meteorology

Harrison,(1) in discussing terminal weather conditions, lists data for Newark, LaGuardia, and Floyd Bennett Field. He brings out the fact that the terrain surrounding Newark favors radiation fog formation, whereas at Floyd Bennett and LaGuardia true radiation fog is rare. The occurrence of thick smoke should be less at LaGuardia than at Newark. Summer ocean fog occurrences at LaGuardia should be greater than at Newark, which is partially shielded by Staten Island.

In his discussion of smoke pollution Harrison brings out the fact that Newark receives smoke pollution with winds from all directions, and that LaGuardia receives from all points but the easterly range between ENE and SSE. Newark, in the five-year period, 1934-1938, exceeded Chicago in number of hours of smoke with winds 0-5 miles mph. It is pointed out that smoke alone may cause suspension of operations at Newark, and that in combination with fog the visibility may be 1/4 to 1/2 mile.

Miller and Mantes,(2) in an attempt to systematize the forecasting of visibility by an empirical treatment of related factors, made studies limited to LaGuardia Field. Trajectories were constructed for four periods of the day during a three-month period (December, 1943 to February, 1944) on the basis of the vector average of the observed wind surface and the pilot balloon wind at the second level (1200-2200 ft.) above the surface. The reciprocal of the visibility was used as a measure of pollution. As a first assumption, it is considered that changes in visibility along the trajectory are probably due to a variation in the concentration of suspended particles. It could then be assumed that having a computed 24-hour trajectory and visibility measurement at the point of origin and at the field, the pollutional increase along the trajectory can be shown. It was further shown in these studies that winds from the SW and SSW at about 5 mph produced the greater evidence of pollution or lowered visibility. Air following this wind path has been subject to metropolitan area pollution for two hours or more, and at that wind speed there is little turbulence to distribute particles throughout a thick layer of atmosphere. The authors concluded that this method of forecasting visibility had about the same accuracy as official forecasts of the same period, and suggest that the simplified procedure offers a method accomplishing about the same result as skilled forecasting by means of mechanical, low-skill operations.

Davidson,(3) a Research Engineer with Consolidated Edison Company in 1942, published results of an 18-month survey in which observations of suspended dust were made at eight sampling stations in Manhattan, Brooklyn, and the Bronx. The principal purpose of this study was to determine the extent to which specific power stations might contribute to the general atmospheric pollution. A method of plotting data on vector polygons or rosettes proved to be a useful tool in tracking local movement of dust pollution. Although caution in interpretation is in order, nevertheless there were certain apparent correlations. For example, the studies suggested that dust concentration expressed as shade number varies inversely as the square root of the wind velocity. It was also shown that even though winter and summer power loads did not vary by a factor of more than 1.5 for about 18 hours out of 24, the shade factors differed by a factor as much as 2.1. It is suggested that seasonal variation of atmospheric dust concentration corresponded to variations in fuel use for heating at the time of the studies. No useful correlation was found between stack number and temperature or humidity.

Carney(4) found an approximately linear relationship between wind speed and visibility at LaGuardia and variation of visibility with wind direction.

U. S. Weather Bureau summary data provide certain essential information. Local climatological data compiled for the airports permit the assembly of such information as temperature, wind speed and direction, psychometric data, sky cover, visibility, and ceiling. These data need to be rearranged for purposes of study of air pollution effects. An arrangement would have to be made with the Weather Bureau to have field observations matched or the alternative would be to take the field observations directly and reduce the

information as required for a specific investigation. Table 1 shows, for example, a comparison of visibility at Idlewild and LaGuardia by months for the year 1955. This table, prepared from Weather Bureau data, indicates that in that year the ceiling at Idlewild was observed at 400 feet, or less—nearly 130% of the frequency observed at LaGuardia. However, the low ceiling was recorded for slightly less than 4% of the total observations made. Critical conditions with 400 feet or less ceiling and 3/4 mile or less visibility were recorded for about 1-3/4% of the observations at Idlewild, and 1% of the observations at LaGuardia. Interpretation of this information is useful only when the occurrence of low visibility conditions can be associated with other meteorological factors, such as wind direction, wind speed, and atmospheric stability.

Table 2, also compiled from Weather Bureau data, shows the distribution of wind observations by quadrants for different ranges of wind speed. It is of interest to note the prevailing or most frequently occurring winds at speeds of 12 miles per hour or less. It has been shown by Miller and Mantes studies[2] that the southwest quadrant winds have well over two hours to pick up any pollution originating from industrial and urban emissions in New Jersey, Manhattan, Brooklyn, and West Queens to bring to LaGuardia and Idlewild a greater concentration of pollutants than would be likely to occur with winds of similar speed from any other quadrant.

Table 2 shows observations of wind speed and direction at LaGuardia during 1955. Winds 12 miles per hour and under accounted for 52.6% of the total observations in that year. The quadrant distribution was NE 13.5%; SE 10.7%; SW 16.4%; NW 11.2%; Calm 0.7%.

As in the previous examination, interpretation is not clear without additional information showing the conditions of visibility occurring under the several wind conditions. However, it is clear that winds of prominence in the low wind speed classification are from the southwest (31.2%) quadrant, and northeast (25.63%) quadrant.

The National Air Transport Coordinating Committee has been conducting studies at LaGuardia, Newark, and Idlewild for well over a year. The data this organization has gathered with cooperation of personnel at each airport contain valuable information.

Each flight is logged and a continuing record is maintained on ceiling, visibility, wind direction and velocity, occurrence of precipitation, haze, fog and smoke. A sample month (June, 1956) was selected from these records in order to examine the types of information that could be obtained by reducing the data. Relationships between visibility conditions and weather conditions can be established from these data.

1955 records of the Port of New York Authority indicate the following average daily runway use:

Airport	Total	Assumed In	Assumed Out
LaGuardia	832	416	416
Idlewild	460	230	230
Newark	394	197	197

The Port Authority records field use for all of June, 1956, as follows:

TABLE 1

Comparison - LaGuardia and Idlewild Airport Visibility by Months - 1955

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total Year No.	Total Year %
	Number of Occurrences (Hourly Readings)													
	A - Visibility 3/4 Mile or Less: Ceiling 400 Ft. or Less													
IDL.	4	12	31	20	20	6	3	14	7	1	11	10	139	1.73
LGA.	1	5	20	14	2	7	1	6	11	0	5	11	83	1.03
	B - Visibility 1-2½ Miles: Ceiling 400 Ft. or Less													
IDL.	0	15	28	15	9	5	2	12	9	7	7	9	118	1.47
LGA.	3	20	35	17	9	4	3	5	10	1	9	9	125	1.56
	C - Visibility 3 Miles or More: Ceiling 400 Ft. or Less													
IDL.	0	11	6	5	7	2	0	15	4	6	2	2	60	0.75
LGA.	0	4	8	6	4	3	1	3	0	4	2	0	35	0.44
	D - Total Observations - Ceiling 400 Ft. or Less													
IDL.	4	38	65	40	36	13	5	41	20	14	20	21	317	3.95
LGA.	4	29	63	37	15	14	5	14	21	5	16	20	243	3.03

Note: Data compiled from Weather Bureau local climatological data New York International and LaGuardia Airports.

Total Observations: IDLEWILD - 8023
1955 LaGUARDIA - 8014

TABLE 2

LaGUARDIA AIRPORT
Wind Direction and Speed
Observations by Months - 1955

Quadrant	Wind Speed mph	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Total
NE	7 -	34	71	40	32	45	66	46	37	55	33	38	89	586
	8 - 12	33	40	39	72	40	48	74	70	82	24	20	52	594
	13 +	56	63	79	182	38	85	84	116	88	82	34	34	941
SE	7 -	18	48	32	26	73	37	42	38	73	41	61	27	516
	8 - 12	5	35	32	41	58	53	37	47	56	30	26	3	423
	13 +	2	24	35	37	46	24	33	106	52	115	13	0	487
SW	7 -	35	45	25	55	81	68	77	64	63	53	34	37	637
	8 - 12	51	47	44	55	64	60	113	97	55	90	45	79	800
	13 +	67	65	114	66	116	60	107	71	55	85	111	74	991
NW	7 -	39	17	15	18	30	36	46	19	17	41	30	29	337
	8 - 12	82	52	40	20	49	91	57	46	29	57	75	49	647
	13 +	318	157	245	113	100	81	22	33	90	84	229	265	1737
	C	4	8	4	3	4	11	6	0	5	9	4	6	64
Total	7 -	130	189	116	134	233	218	217	158	213	177	167	188	2140
	8 - 12	171	174	155	188	211	252	281	260	222	201	166	183	2464
	13 +	443	309	473	398	300	250	246	326	285	366	387	373	4156
Total		744	672	744	720	744	720	744	744	720	744	720	744	8760

NOTE: Information summarized from U. S. Weather Bureau local climatological data.

Airport	Total No.	Average No. Flights per Day Takeoff	Landing	Total
LaGuardia	20,746	346	345	691
Idlewild	13,444	224	224	448
Newark	11,158	187	185	372

It will be observed from the above records that regardless of weather or restricted visibility conditions the daily averages for field use are not too widely divergent. It follows that delays in takeoff which may be due to local and temporary conditions cannot be assessed from the general records of airport use.

A review of one month's (June, 1956) records obtained by the Coordinating Committee shows field use on days of restricted visibility or fog, smoke and haze at the three airports to be:

Airport	No. Days with Restricted Visibility	Range of Field Use Total Flights Daily Min.	Aver.	Max.
LaGuardia	28	540	718	884
Idlewild	15	380	452	529
Newark	14	331	396	500

A record of the fourteen days of restricted visibility at Newark is presented in Tables 3 and 4.

During June, 1956 restricted visibility prevailed for at least 15% of the total month. During the periods of restricted visibility the ceiling was 800 feet or less 75% of the time; the visibility was three miles or less 64% of the time; the wind was 15 miles per hour or less 92% of the time; and smoke or haze was directly involved in the condition 32% of the time. 1415 aircraft, or 25% of the total for the month, used the field during the period. Average use per hour varied from 6 to 38 and averaged 13 during the restrictive period compared with a range of 13 to 19 per hour, and an average of 16 per hour for the 14 days during which restrictive conditions were observed.

Records such as these correlated with air pollution measurements are valuable in tracing out the effects of pollution (both natural and man-made) on airport traffic. Additional micrometeorological studies must be made concurrently with pollution measurements in order to isolate the several factors which bear on the occurrence of restricted airport visibility.

Possible Sources of Pollution

Investigations included a study of zoning maps obtained from the New York City Department of Planning and helicopter flights over the metropolitan area through the courtesy and cooperation of the Port of New York Authority.

The New Jersey State Health Department has conducted surveys of the air pollution emanating from open burning in the vicinity of Newark airport. In 1954 a preliminary study was made at Newark airport to establish any correlation that might be found between particulate matter, density and visibility recorded by the Weather Bureau. Unfortunately, the Department was not able to pursue these studies to any conclusion. Data obtained are too meagre to be useful. They do, however, indicate that carefully controlled studies in which

TABLE 3

Newark Airport June, 1956

Observations During Periods of Restricted Visibility

Date	Total Min. Restricted	Ceiling 800 ft. or Less Min. H or KH	K	F	R	RF	FK	Comb. of RFKH	Min. Visibility 3 M or less	Wind Velocity mph 0-5	6-15
June 1	81						81		81	81	
2	765				18		102	543	623		530
3	672			221		86	117	248	90		672
4	387	52	28				307		387	265	122
7	286	154					132		286	249	
9	985	121		53		183		30	213		985
10	854	159				228	79	62	387	854	
11	427						426		427	132	295
12	63		59						59	63	
14	38								37		38
21	1091		36		125	734			790	167	647
22	198						119		198	64	134
24	486			68	100	134			486	320	166
27	348		102				64	51	227	237	111
Total - 14 days	6681	486	225	342	243	1365	1427	934	4291	2432	3700
		5022								6132	
Total (14 days) Hours	111.35	8.10	3.75	5.70	4.05	22.75	23.78	15.57	71.52	40.53	61.67
		83.70								102.20	

Percent of Restricted Visibility Time

Ceiling	800 Ft. or less	=	75.2
Visibility	3 miles or less	=	64.2
Wind	15 mph or less	=	91.8
Smoke or Haze	involved directly	=	32.0

Ratio Restricted Time / Total Month = 111.35 / 720 = .1546

NOTE: Data based on information taken from National Transport Coordinating Committee Preferential and Runway Use Data

Symbols: H - Haze
K - Smoke
F - Fog
R - Rain

TABLE 4

Newark Airport

Field Use During Periods of Restricted Visibility

June, 1956

Date	Restricted Visibility Quarter of Day	Mins.	Use During Restrictive Condition TO	L	Total	Aver. No. Per Hour	Daily Total No.	Ar. No./Hr.
1	NM	81	25	26	51	38	415	17
2	NMAE	765	87	115	202	16	332	14
3	NM	672	62	37	99	9	344	14
4	NM	387	53	49	102	16	423	18
7	NM	286	53	45	98	20	433	18
9	NMAE	985	99	91	190	12	308	13
10	NME	854	62	71	133	9	331	14
11	NM	427	30	39	69	10	500	21
12	N	63	1	6	7	7	454	19
14	M	38	13	8	21	33	448	19
21	NMAE	1091	137	124	261	14	348	15
22	NM	198	19	16	35	11	441	18
24	NM	486	26	20	46	6	338	14
27	NM	348	51	50	101	17	424	18
TOTAL		6681	718	697	1415	13	5539	16

CODE: Quarter of Day Restriction Occurred

N	Night	0000 - 0559
M	Morning	0600 - 1159
A	Afternoon	1200 - 1759
E	Evening	1800 - 2359

particulate matter trapped on filter paper is measured either by light reflectance or transmittance procedures, may be helpful in establishing the amount of pollution due to particulates producing critical visibility conditions.

Hemeon(5) and co-workers have shown that if sampling is controlled to produce optical densities of about 0.3 or less, Beer's law will apply, and a linear relationship between light transmittance or reflectance will obtain.

Helicopter Flights

Two helicopter flights were made. One, November 15; the other, November 23, 1956. The first was confined to the vicinity of LaGuardia and Idlewild, but the second included a tour over all three airfields. On November 15 the weather was overcast, the wind, WNW. Haze was observed, but the visibility was reported as ten miles. Observations were made of possible industrial and municipal sources. No stack emissions of consequence were noted.

On November 23 the weather was reported clear, visibility 15 miles plus, wind, WSW 10 at LaGuardia. The field was clear, although haze was noted at distance. Several emission sources were noted. Points along the Pennsylvania Railroad in New Jersey seemed to be first contributors to a haze condition formed and moving ENE increasing in density as it crossed Staten Island, lower Manhattan, and Brooklyn. The southern edge of the haze line was not as distinct as the northern line previously mentioned. It spread across Staten Island and Raritan Bay. Idlewild airport reported visibility 15 plus on ground, but slant visibility was restricted. The top of the haze mass was about 5,000 feet. Winds were reported from Idlewild at 15 to 20 WSW at this time. At the same time, Newark airport was clear; LaGuardia remained clear, but the haze spread easterly over Idlewild and Nassau County.

There was a definite indication that with winds from the WSW or SW quadrant a general condition of increasing haze could be anticipated beginning at the westerly fringe of industry in New Jersey and moving easterly with increasing density. It could be anticipated that with winds from the east the haze might begin over the eastern fringe of New York and move westerly with increasing density, since there are numerous contributors to atmospheric pollution lying in the pathway. The studies of Miller(2) previously mentioned tend to be supported by these visual observations.

There is no justification for singling out any one industry or municipal source of smoke emission for special note as the basic cause of haze or smog over the New York metropolitan area. It is obvious that localized sources (1-5 miles radius of field), even though contributing, are only adding to a general accumulation of haze-producing substances. The area to be considered in assessing the total haze accumulation must extend from Nassau County on the east to a general line west of urbanized and industrialized developments in New Jersey.

Airfield Sources of Hydrocarbons

Table 5 summarizes the information received from airlines concerning fuel requirements for on and off time taxi. At any airport there are periods of time when engines must run. These include (1) warm-up prior to takeoff; (2) taxi time out and waiting for takeoff; (3) takeoff; (4) landing and ground taxi to terminal position; (5) taxi to or from hangar to terminal position; (6) testing after repair.

The figures on fuel use are absolute minimum and probably are less than

TABLE 5

New York Metropolitan Airports

Estimated Fuel Consumption During Landing and/or Takeoff

June, 1956

Line	LGA Use No. Flights	LGA Fuel Gals.	IDL Use No. Flights	IDL Fuel Gals	IDL Time Hrs.	EWR Use No. Flights	EWR Fuel Gals.
Flying Tiger	0		68	9,114		129	15,351
Capitol	?		?			?	
North East	?	3,610	0			0	
El Israel	0		26	232	3.86	0	
Varig	0		?	2,200		0	
A A L *	3296	78,280	748	25,681		572	11,495
Delta *	0		0			416	20,101
National *	0		522	36,717	94.5	0	
U A L	1020	25,500	780	22,860		1140	20,400
P A A *	0		903	36,120	150.5	0	
KLM	0		118	3,165	19.2	0	
Mohawk *	0		0			443	6,508
Scandinavian *	0		90	1,800	24.0	0	
Total Estimated		107,390		137,889			73,855

* Departures only

NOTE:
Data recorded or estimated is based on replies to letter questionnaire.

half of the total taxi use for the month of June, 1956. Nonetheless gases from the combustion of 107,390 gallons of fuel were exhausted at LaGuardia, 137,890 gallons at Idlewild, and 73,860 at Newark—a total of about 319,000 gallons for one thirty-day period. Since five of the reporting companies offered records on departure only, and only one included any allowance for warm-up and hangar taxi time, it seems reasonable to estimate double the quantity of fuel as a possible contributory factor to aerosol formation and possible fog persistence.

One of the airlines furnished a complete breakdown of departure time for its operations at Idlewild for the month of June, 1956. Time ranged from four minutes to 59 minutes for flight takeoff. The average for all flights for the month at Idlewild was 11 minutes per takeoff. Two companies furnished time for departures at Newark. One indicated an average of 9.5 minutes; the other, 9.4 minutes per takeoff. The maximum time for takeoff was 60 minutes.

The companies show some variation in figures for fuel consumption by the several types of aircraft. One company has estimated the consumption on a rated basis.

DC 7 types	-	9 gals. per minute
DC 6 types	-	7 gals. per minute
Convair 340	-	3 gals. per minute

The fuel consumption with average takeoff time of about ten minutes would then be:

DC 7 types	-	90 gals. per takeoff
DC 6 types	-	70 gals. per takeoff
Convair 340	-	30 gals. per takeoff

A Convair taxiing 24 hours a day would consume about 129,600 gallons per month, which is comparable to the reported fuel consumption at both LaGuardia and Idlewild.

The amount of fuel used should be a matter of economic concern to the airlines. It is certainly of further interest for research investigation on the exhaust hydrocarbon characteristics. This possible source of nucleation may be one of the factors contributing to fog persistency at the airports.

Mechanism of Pollution Formation and Persistence

Sources of Contaminants

Atmospheric contaminants include the combustion products of the fuels, effluents from chemical and metallurgical processes, refineries, stock yards, refuse disposal, and motor transportation. The contaminants from these processes exist in the atmosphere as gases, vapors, dusts and fumes. Gases or vapors include the permanent gases as well as the compounds that boil below 300° C, which when present in low concentrations exist only as vapor.

The common contaminants of gaseous origin include sulfur dioxide and its oxidation products, sulfur trioxide and sulfuric acid, oxides of nitrogen, carbon monoxide, a large number of organic compounds from the combustion of fuels and ozone.

Properties of Aerosol

Investigations of the relationships between air pollution and fog have shown that the persistence of fogs is generally greater where air pollution is present than it is in relatively pure country air.(6) This phenomenon has been attributed to the difference in the type of aerosol.

The term aerosol is used to designate liquid or solid submicron particles dispersed in a gaseous medium.(7) Its most important properties are that it can be seen and that it will obscure objects from view.(8) When the concentration of aerosol pollution increases, the loss of visibility will frequently restrict airport operation and at times affect automobile traffic. The particles do not form a barrier to light but reduce visibility due to light scattering. The amount of light that is scattered and therefore the contribution of the aerosol to obscuration depend not only on the number of particles per unit volume but very much on the particle size and on the refractive index of the material. The most effective size for light scattering by most liquid aerosols is when the drop size is from 0.3 to 0.6 microns diameter.(9) Large drops are less effective in scattering light, but they remove light by absorption and therefore contribute to obscuration. The blue haze which is characteristic of many polluted atmospheres is usually associated with aerosols of very small particle size near the lower range of the wave length of visible light.

With an average particle diameter of 0.5 microns and a very dilute aerosol with a visibility of perhaps three miles, Johnstone(8) estimates the concentration would be about 0.1 mg./cu.m. For particles of unit density this would correspond to 1,600 particles per cc. (45,000,000 per cu. ft.). If the concentration of particles is increased tenfold, the visibility is only 1,600 feet, and the mass concentration in the order of 1 mg./cu.m. The droplets in a natural fog are much larger, ranging from 5 to 50 microns in diameter. Such fogs seldom contain more than 5 drops per cc. A fog containing 200 mg./cu.m. has a visibility of about 500 feet.(10) Light scattering efficiency per unit mass of material for the large drops is much less than that of the submicron droplets.

Various kinds of nuclei are present in the atmosphere and at the slightest degree of supersaturation condensation on the nuclei begins. In the vicinity of the ocean salt nuclei are the means for condensation and in industrial atmospheres sulfuric acid mist, hydrocarbons and other contaminants may provide the means of condensation. In cases of incomplete combustion of fuels, such as smoking oil or coal, haze forms that persists for a long time after the fog has settled out. Fogs produced under these conditions tend to last longer than those involving nuclei from complete combustion processes.

Fog persistence increases continuously with increase in the number of nuclei. With increasing nuclei content of the air the radius of the resulting fog droplets diminishes while the number of drops increases. However, the number of nuclei that participate in the condensation process, on the average, decreases with the higher concentrations.

Electrostatic charges on the droplets represent a possible explanation of the smaller drop size and consequently greater duration of the fogs, particularly in view of the fact that the production of aerosols by combustion processes is connected with strong ionization. The acquisition of electric charges by the fog droplets stabilizes the fogs by reducing coalescence, provided the charges reach a critical value which is less for small than for large droplets. With increase in nuclei concentration the number of available electrostatic charges increases, so that coalescence of fog droplets becomes less likely.

Under this condition the drops remain small and their sedimentation is retarded. The prerequisite is probably fulfilled by the ions produced by the combustion process. Outdoors, nuclei usually carry electric charges with one polarity preponderant.

Significance of Sulfur Dioxide as an Air Contaminant

It has been estimated that 28.7 million metric tons of elemental sulfur was emitted to the world's atmosphere(9) in a recent year from the combustion of coal, smelting of ores, and the production and consumption of petroleum. Two thirds (25.7 million metric tons) of this amount was released in relatively low concentrations in the combustion of coal.

In the smelting of ores and the burning of conventional fuels the sulfur, present in whatever form, is usually oxidized to sulfur dioxide. In the refining of petroleum part of the sulfur is removed with the refinery gases as hydrogen sulfide. If this mixture of refinery gases is burned without further processing, the hydrogen sulfide is oxidized principally to sulfur dioxide. Invariably in the production of sulfur dioxide in the combustion process, a small quantity is oxidized to sulfur trioxide (SO_3) which hydrolizes in the atmosphere to produce sulfuric acid (H_2SO_4) mist.

Sulfur trioxide in the gases leaving the furnace may not exceed 1 per cent of the sulfur dioxide present, but it is responsible for the characteristic blue plume. The particle size of sulfuric acid mist(11) varies from 0.5 to 5 microns depending upon moisture available for growth of the particles. If the particles are of 0.5 microns diameter and of unit density, an aerosol containing 1,600 particles per cc. (45,000,000 per cu. ft.) will reduce visibility to 3 miles.(8) If the number of particles is increased tenfold, the visibility will be 1,600 feet. Particles of this size are near the optimum size for scattering of light.

Oxidation of Sulfur Dioxide in Fog Droplets

The rate of oxidation of sulfur dioxide to sulfuric acid aerosol is believed to be greater in the presence of a fog containing a trace of manganese or iron catalysts. A study was made by Coughanowr(12) on the absorption and oxidation of sulfur dioxide from humidified air mixtures by stationary water droplets containing small amounts of manganous sulfate. The experiments were made by exposing single droplets to humidified air containing a known concentration of sulfur dioxide for a measured interval of time. The quantity of sulfuric acid formed in the droplet was determined by diluting the droplet with water and measuring the conductance in a microconductivity cell.

Coughanowr continued the work on the absorption of sulfur dioxide by droplets containing other catalysts which may be present as nuclei in natural fog. The catalysts used were ferric sulfate, ferrous sulfate, nickelous sulfate, and manganous sulfate containing ferric sulfate or cupric sulfate. Iron sulfate was of special interest because particulate matter containing iron dust is common in industrial communities and ferric sulfate is an effective catalyst in the liquid-phase oxidation of sulfur dioxide. The rate of oxidation of sulfur dioxide in droplets containing ferric sulfate was much slower than for droplets containing manganous sulfate.

Effect of Air Pollution Control Measures in St. Louis

The average sulfur dioxide concentration in downtown St. Louis during the

winter months of 1936 varied between 0.10 and 0.50 ppm. Following the introduction of air pollution control measures sulfur concentrations in downtown St. Louis during the winter months of 1950 varied between 0.03 and 0.06 ppm. Similar comparisons are available for the summer months of the two years under consideration. Schueneman[13] concludes that sulfur dioxide concentrations were 83% lower in the winter and 73% in the summer of 1950 than for comparable periods of 1936-37.

Sulfur dioxide concentrations now found in the downtown areas are comparable to those found in suburban areas 1 to 20 miles from the city 13 or 14 years ago. Repainting need not be done so frequently and stone and metals do not suffer corrosion damage as formerly. Plants which could not be grown within the city in 1936 are now as hardy there as in the outlying areas.

The diurnal variations of sulfur dioxide concentrations also reflect the marked reductions of 1950. The author attributes the improvement to the use of lower sulfur coals in hand fired equipment, reduction of sulfur in stoker coals by washing, and the use of lower sulfur fuel oils and natural gas.

Role of Combustion Products and Sunlight in Air Pollution

About 5 years ago A. J. Haagen-Smit[14] of California Institute of Technology offered an explanation of the origin of the Los Angeles smog. He suggested that the hydrocarbons in the air could be oxidized to produce the compounds which would damage plants and cause eye irritation and produce a smoke screen. Some 50 compounds possibly present in the air were tested on their ability to cause smog damage to plants without success. However, when the reaction products of ozone with unsaturated hydrocarbons were tried, typical smog damage resulted.

The ozonization was carried out in vapor phase by bringing the vapors of the hydrocarbons into contact with the ozone. When the two streams met, a dense aerosol was formed which had a marked light scattering effect and drastically reduced visibility. As a source of the hydrocarbons ten-degree fractions of a cracked gasoline were used. (Most gasoline now available is cracked and contains 20% of olefins or unsaturated hydrocarbons. The straight run gasoline formerly used contained no more than 1% of olefins.)

It is concluded that the organic material, mostly hydrocarbons, released into the air is oxidized by the ozone initially present, by the action of oxygen and sunlight, and by the catalytic action of the nitrogen dioxide and nitrogen oxide cycle releasing atomic oxygen under the influence of the sunlight. These oxidations produce peroxides, aldehydes, and acids, and aerosols are formed which decrease visibility and may be a source of eye irritation.

Automobile Exhaust

Benoliel and Magill[15] studied the composition of exhaust gases from a blocked engine under simulated operating conditions and from operating vehicles. From these studies they estimated the amounts of chemicals from this source going to the air in Los Angeles. The condensates and materials frozen out were analyzed for aldehydes, acids, nitrogen oxides in solid carbonaceous materials, and volatile organic matter.

The authors report that the most significant emission is volatile organic compounds, representing approximately 3.5% of the gasoline consumed. The initial method of collecting and analyzing samples measured hydrocarbons boiling below C_5 (approximately 40° C.), but discharge of hydrocarbons in the

range from methane to butane and butylene may increase losses through the exhaust to 10 to 20% of the gasoline entering the carburetor.

The emission of organic material and oxides of nitrogen varies considerably with engine operating conditions. When idling, accelerating, or decelerating, combustion is less efficient (and the organic emission relatively much greater) than at constant speed operation. Emission of the oxides of nitrogen is greatest under power conditions, which is attributed to higher combustion temperatures. It is concluded that the oxides of nitrogen are produced by the fixation of atmospheric nitrogen during the combustion, since hydrocarbons free of organic nitrogen compounds produce similar quantities of nitrogen oxides when used in lieu of gasoline.

Incineration of Garbage and Rubbish

Poorly designed domestic, industrial and municipal incinerators and burning dumps are a recognized source of air pollution. The burning of heterogeneous materials under a variety of conditions can be expected to release a complex mixture of products capable of taking part in smog-forming reactions.

Studies by the Los Angeles Air Pollution Control District, Stanford Research Institute and Battelle Memorial Institute have indicated that a substantial portion of the incinerator effluents are organic materials. Aldehydes, ammonia, nitrogen, oxides, methane, ethylene, benzene, olefins, and acetylene are present in significant quantities. Appreciable quantities of acetone, methanol, carbonyl sulfide, organic acids and phenols are present. Excluding carbon monoxide, carbon dioxide, and water, the amount of these materials released to the atmosphere ranges between 82 and 407 lbs. per ton of material burned. The incineration of a ton of paper has been shown to produce 145 lbs. of organics and a ton of grass clippings, 415 lbs.

Summary of the Existing Situation

The metropolitan area of New York City had a population in 1950 of 12,912,000, including 3,356,000 in New Jersey. A 1954 industrial census indicates that there are 51,628 industries (Census Bureau Classification) in the area.

It is recognized that not all industry contributes to air pollution because of its industrial processing; however, population and industry do contribute to the air the combustion products arising from requirements for heat. Power is, of course, a prime requirement for industry and public transportation.

Generation of power for rapid transit is a major item in New York City. Thousands of buses travel the public ways and these are contributors of hydrocarbons constituting a serious addition to the pollution load of metropolitan areas. Apartment house incinerators are required by law in New York City. Even though the New York City Department of Air Pollution Control is performing a magnificent work in reducing pollution from incinerators, the aggregate contribution adds to the general level of air pollution.

Open burning of factory refuse both in New York and New Jersey areas constitutes an observable increase in pollution.

The idling engines of aircraft during warming up periods, taxiing, and testing contribute the gases and vapors of thousands of gallons of burned fuel each day directly to an airport area.

Weather producing fog accounts for a material proportion of the time of low ceiling and low visibility. However, there are occasions during which the

weather is not fog producing and yet visibility is low. Interference with transverse or diagonal visibility during aircraft landings is a definite factor by observation, but it is not measurable by the usual methods, nor does it necessarily appear in the records as an effect on horizontal visibility or lowered ceiling. The haze affecting transverse visibility may extend from 500 to 5,000 ft. above the ground. Particulate matter, mists, vapors, and fumes in the air, when combined with natural fog, presumably create a more dense mass of aerosol, which is more persistent than either the air pollution which may be dissipated rapidly by atmospheric turbulence and an increase in mass air velocity, or fog, which may be dispersed rapidly following a change in climatological conditions.

Aerial observation of the smog condition indicates that there is no single localized source of emission that will account for all of the non-visibility conditions created at any of the airports. Idlewild, for example, has very little industry in proximity to it, and yet non-visibility conditions due to smog and fog occur with disturbing frequency.

Newark airport is perhaps the most severely affected by local conditions. There are occasions when the combination of smoke from burning refuse and emissions from nearby industry have created hazardous conditions of low visibility at that airport, while areas nearby and out of the flow of air from these sources remained clear.

Investigation of the relationships between air pollution and fog has shown that the persistence of fogs is generally greater where air pollution is present than it is in relatively pure air. Aerosol contaminants may produce fogs with much greater obscuring power than is obtained by clean-water fog. Fog persistence increases continuously with the increase in the number of nuclei. Condensation nuclei may be of natural origin or may arise from the activities of man.

The continuation of conditions affecting the metropolitan airports of New York City is incompatible with the need for safe, rapid, and continuous aircraft service to the area. Improvement in the situation is a prerequisite of expanded airline service. Until the improvement in airport visibility is achieved, flights must depend on instrument flying during periods of critical visibility.

ACKNOWLEDGMENT

Although the Research Division staff have had the responsibility of searching out and compiling information that has been included in this report, it would have been impossible to accumulate much of the data without the cooperation and assistance of numerous individuals, agencies and airline companies. All of those who have helped are offered our appreciation of their interest.

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REFERENCES

1. Harrison, H. T., "Terminal Weather Conditions," United Air Lines Transport Corporation Report (1941).

2. Miller, James E. and Mantes, Homer T., "An Objective Method of Forecasting Visibility," The Bulletin of the American Meteorological Society, 29, 5, 237 (May, 1948).

3. Davidson, M. F., "A Study of Atmospheric Pollution," Monthly Weather Review, 70, 225 (Oct., 1942).

4. Carney, C. B., "Aids in Forecasting Minimum Visibilities in Smoke at LaGuardia Field, N. Y.," Unpublished (1944).

5. Hemeon, W. C. L., Haines, G. F., and Ide, H. M., "Determination of Haze and Smoke Concentrations by Filter Paper Samplers," Air Repair, 3, 1, 22 (Aug., 1953).

6. Neuberger, Hans, "Air Pollution and Fog Properties," Proceedings of the United States Technical Conference on Air Pollution, McGraw-Hill Book Co., N. Y. (1952).

7. Rodebush, W. H., "Aerosols in the Atmosphere," Proceedings of the United States Technical Conference on Air Pollution, McGraw-Hill Book Co., N. Y. (1952).

8. Johnstone, H. F., "Properties and Behavior of Air Contaminants," Proceedings of the United States Technical Conference on Air Pollution, McGraw-Hill Book Co., N. Y. (1952).

9. Sinclair, D. and LaMer, V. K., "Light Scattering as a Measure of Particle Size in Aerosols," Chemical Review, 44, 245 (Apr., 1949).

10. Houghton, H. G., Radford, W. H., "Papers and Physical Oceanography and Meteography, Woods Hole Oceanographic Institute, 6, 4 (1938).

11. Katz, Morris, "Sulfur Dioxide in the Atmosphere and Its Relation to Plant Life," Industrial and Engineering Chemistry, 42, 11, 2258 (Nov., 1950).

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DISCUSSION
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MECHANISM OF REAERATION IN NATURAL STREAMS[a]

Closure by Donald J. O'Connor and William E. Dobbins

DONALD J. O'CONNOR,[1] J.M. ASCE and WILLIAM E. DOBBINS,[2] M. ASCE.—The writers greatly appreciate the discussions which have been presented. They have greatly contributed to the understanding of this problem and its application.

Mr. Camp commented on the great difference between the sulfite tests and the aerated water tests and further indicated that the sulfite test should not be used to determine the liquid film coefficient for gas transfer, although it has been used widely for the comparison of efficiencies of different aeration devices. The writers fully agree with this point and appreciate his clarifying discussion of process in a sulfite solution. In stating that the method has been recently criticized, the writers had reference to a recent work in the fermentation field(39). This case has also been treated mathematically by Danckwertz.(2)

Mr. Camp has contributed to this field of knowledge by his discussion of bubble aeration and the application of the theory of this case. His expression for the renewal rate for bubbles incorporates the velocity and diameter of the gas bubble. It would appear, however, that some measure of the scale of the fluid turbulence should be included. His analysis of Ippen's data is significant, particularly in showing the effect of detergents on the transfer coefficient.

The writers are in complete accord with his comments on the relative effectiveness of bubble and surface aeration in present practice.

Messrs. Camp and Diachishin have both pointed out that the author's equation (35) for the non-isotropic case may be expressed in a form in which the exponent of H is equal to 3/2 as in the isotropic case. The authors have been aware of this but prefer the form of equation (35) since it eliminates the factor C, which is difficult to estimate for any practical case, and expresses k_2 in terms more readily available as measurable parameters. The velocity term, which appears in Mr. Camp's equation (35a) and Mr. Diachishin's equation (43), which are equivalent, is a function of the slope, depth and some parameter which characterizes the roughness of the channel. Hence equations (35a) and (43) are not really in their most fundamental form. For example, if Manning's expression for C is introduced into equation (35a), the resulting expression for k_2 will take the form

$$k_2 = \frac{480\, n^{\frac{1}{2}}\, D_L^{\frac{1}{2}}\, u^{\frac{1}{2}}}{(1.486)^{\frac{1}{2}}\, H^{19/12}}$$

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a. Proc. Paper 1115, December, 1956, by Donald J. O'Connor and William E. Dobbins.

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Since the roughness coefficient, n, itself undoubtedly varies with H, the actual functional relationship between k_2 and H for a given river is actually not defined precisely by any of the equations so far presented. Except for convenience or comparative purposes there appears to be no real justification in using the exponent of H as 3/2 for the non-isotropic case, simply because it makes it agree with the exponent for the isotropic case. It must be remembered that the equation for the latter case was based on some very simple assumptions derived from empirical measurements—i.e. the mixing length and the vertical velocity fluctuation are 10% of the average depth and flow velocity, respectively. In the paper the writers pointed out that any theory which takes into account the roughness elements is the most appropriate for natural rivers. However, owing to the inadequacies of the existing theories for river flow, the writers preferred to put the expression for k_2 in the form which eliminates the necessity for estimating the values of the bottom roughness parameters. Mr. Diachishin is, therefore, in error when he states that for both cases the reaeration coefficient is inversely proportional to the 3/2 power of the depth. Also, maximum k_2 values will not necessarily occur at minimum depths, as is indicated by the data in Table V, both calculated and observed.

The writers agree with Mr. Diachishin's comments on the sources of inaccuracy in reported values of reaeration coefficient, particularly with regard to the oxygen factor of life forms not necessarily involved in the purification process. It is strongly emphasized that the theoretical development makes no attempt to incorporate this factor. Therefore, comparison of theoretical to observed coefficient, where this factor is present, is not valid and such data neither proves nor disproves the theory. It is rather surprising that Mr. Diachishin, after appreciating this factor, then ignores it in comparing values on the lower Little Tennessee.(38) He compared an observed value of 10 per day to a calculated value of 1.28 per day. The observed value was based on data collected during daylight hours.

In this regard, the author(38) states: "The D.O. varied between 5.85 ppm and 6.90 ppm, apparently due to oxygen added during the daylight hours by algae," and ". . . and also brings out the increase in (reaeration) rate during daylight hours, due to the addition of oxygen by algae." In using a value of 10.0, Mr. Diachishin is measuring the combined effects of reaeration and algae. In order to test the theoretical equations, the darkness values would be more representative. The data for the night condition were given, from which an observed reaeration coefficient was computed as 5.3 per day. In calculating the theoretical reaeration coefficient for this river, the following quotation from the same report is pertinent: "This width varies between 600 and 1200 feet and the mean depth at 7000 cfs is on the order of 3.5 in the narrow sections and 1.5 feet in the wider reaches. Water velocities vary from 3.2 feet per second in deeper reaches to 4.2 feet per second on the broad shallow shoals."

Mr. Diachishin in reporting a calculated value of 1.28 per day, apparently ignored the shallow sections and based the computation on the deep section, only. Such a calculated value obviously is not at all representative of the river stretch. When the reaeration coefficient is computed for each section and weighted according to the length of each section, the average value is 4.8 per day, as compared to an observed value of 5.3 per day.

Mr. Diachishin discussed the Ohio River survey data(1) and presented one example of the lack of agreement between the observed and calculated values.

The mean depth was determined by adding to the stage height a depth correction. The stage height referred to depth above low water and since the average depth from low water to channel bottom was significant, a depth correction of 1/2 this value was added to the stage height. This procedure was followed to obtain a value of depth which best represented the ratio of the volume to the surface area. This procedure is justified if the depth correction is low; however as this value increases, the possible error is significant. In the case Mr. Diachishin examined, the depth from low water to the channel bottom was 11.7 ft. It is doubtful that the representative depth could be determined for stretches when the correction was based on a value as significant as this. Consequently, the writers do not include sketches where the correction was of this order, in spite of the fact that there was reasonable agreement between calculated and observed values in some of these cases. In addition, the slope of the sketch varied markedly as was indicated in the original work, which introduces another possible source of inconsistency. There were other sources of inaccuracy in these data as indicated in Tables IV and V. Obviously, such data can be used neither to confirm nor to refute the theoretical development. These points were presented originally, but in view of Mr. Diachishin's discussion, it was felt that they were worth repeating.

Mr. Diachishin comments that the Ohio River data is "hardly a verification of the theory", because observed minimum reaeration coefficients occur at other than maximum depths and the theory indicates otherwise." This is quite possible both in theory and practice, as indicated above.

Mr. Diachishin's analysis of the experimental data is appreciated and the writers agree with his conclusion that the range of speeds was too limited to indicate the relationship between the speed and reaeration coefficient.

In reference to another experimental study,(28) it was believed that the data were not representative of the conditions, which were used as a basis for the theoretical development. Flow was induced by virtue of a longitudinal propeller located in one of the channels. Surface renewal would be due to not only the turbulence of flow but also to rotary motion induced by the propeller. Furthermore many of the tests were carried on under laminar flow conditions. Experiments were also conducted on depths of flow of 9, 12, and 15 inches. Mr. Diachishin indicated that the conclusion showed no influence of depth on the reaeration coefficient. In the case of the 9-inch depth of flow, the propeller was breaking the surface and the authors(28) themselves express some doubt about this data. It would appear that for the same velocity a greater speed of the propeller would be required for a greater depth, thus masking out the influence of depth in that particular experiment.

Mr. Pasveer objects to the two-film theory because, "it obscures the fact that according to the theory of diffusing the quantity diffused is proportional to the square root of the time and not to the time." The objection does not seem valid since the overall transfer coefficient, K_L, as applied to a turbulent liquid, is actually a constant in the statistical sense; and the total quantity of gas absorbed increases directly with time as long as C_L remains constant. To clarify this it is necessary to distinguish between time in its general sense and the particular interval of time which is the average time of renewal of the surface. The latter is equal to 1/r and is a constant for any particular intensity of turbulence at the interface.

The equations presented by Mr. Pasveer result from the solution of the general differential equation for absorption of gas into a quiescent liquid (equation 9) under the boundary conditions:

$$C = C_L, \text{ when } Y > O, t = 0$$

$$C = C_S, \text{ when } Y = 0, t > 0$$

$$C = C_L, \text{ when } Y = \alpha, t > 0$$

The concentration, C, at a distance, Y, below the surface is given by

$$C - C_L = (C_S - C_L) \operatorname{erfc}\left[\frac{Y}{2\sqrt{D_\ell t}}\right]$$

and the rate of transfer of gas across a unit area of interface is given by

$$N = (C_S - C_L) \times \sqrt{\frac{D_\ell}{\pi t}} \tag{11}$$

Thus the instantaneous rate of transfer decreases with time for any period of time during which the liquid remains quiescent.

The total amount of gas carried across the interface during an interval of time t' is given by

$$\int_0^{t'} N\,dt \text{ which is equal to}$$

$$2\,(C_S - C_L)\sqrt{\frac{Dt'}{\pi}}$$

This is Mr. Pasveer's equation for Qd. The average rate of transfer during this time, t', will be the total amount divided by t' which is given by

$$N = 2\,(C - C)\sqrt{\frac{D_\ell}{\pi t'}}$$

It is obvious, now, that if the quiescent condition assumed prevails for the time, t', and the whole mass of the liquid is then instantaneously mixed, this process being repeated indefinitely, the overall average rate of transfer will be as given in the equation above. If the time of renewal, t', is replaced by the rate of renewal, 1/t' = r, the equation for the average rate of transfer is

$$N = \frac{2}{\sqrt{\pi}}\,(C_S - C_L)\,\sqrt{D_\ell r}$$

and

$$K_L = \frac{2}{\sqrt{\pi}}\,\sqrt{D_\ell r}$$

This is seen to be a constant, $\frac{2}{\sqrt{\pi}}$, or 1.13, times the value of K_L used by the authors (equation 27).

It is to be noted that the writers' equation (27) was derived by neglecting factors of minor significance in either of the two equations (25) or (26). It is significant that equation (25) was derived from boundary conditions based on a liquid film, whereas equation (26) was derived from boundary conditions similar to those advocated by Mr. Pasveer. Thus, it makes little or no difference whether or not the liquid film is assumed to exist. The factor, $\frac{2}{\sqrt{\pi}}$, which is the ratio of K_L as obtained by Mr. Pasveer's approach to that obtained by the writers' approach, is due to the fact that the writers used Danckwert's age

distribution function[11] in their development, whereas Pasveer assumes that the surface replacement takes place at the same time over the entire surface. It would seem that the first assumption is a closer representation of the actual physical conditions at the surface of a stream. The remarkable thing is not that these two different approaches result in different values for K_L but that the expressions for K_L differ only by a constant factor equal to 1.13.

Mr. Pasveer's reference to Stafan's investigation of the conditions, under which the formulas evolved by him are applicable, is pertinent. The writers are in agreement with him in this regard.

Mr. Rand discussed some pertinent factors concerning reaeration in natural bodies of water, such as wind action and thermal convection. The writers agree that the approach used may be applicable to these cases, particularly in the case of wind action. His discussion of the so-called "heaving surface" is of particular interest. This condition may be represented by oceans and flow over rapids. The writers agree with Mr. Rand that the assumption of instantaneous saturation upon exposure of a new element of surface may impose a limitation on the condition of a "heaving surface." In addition, air bubbles may be entrained and the transfer may be controlled by a different mechanism in this case.

The effect of temperature on the reaeration coefficient, with a temperature coefficient of 1.016, was referenced incorrectly in the paper. This relationship is as shown in Fair and Geyer,[40] based on Becker's work. The coefficient indicated by the original reference[28] is 1.047. There is no apparent reason to explain this difference; work is being carried on at the present time which should clarify this issue.

In conclusion, the writers express their appreciation of the discussions submitted and in particular of the suggestions leading to other applications of aeration.

REFERENCES

39. Schultz, J. S. and Gaden, E. L., "Sulfite Oxidation as a Measure of Aeration Effectiveness," Industrial and Engineering Chemistry, 48, No. 12 (December 1956).

40. Fair, G. M. and Geyer, J. C., "Water Supply and Waste Water Disposal," John Wiley Inc., New York (1954).

SOME ENGINEERING ASPECTS OF HIGH-RATE COMPOSTING[a]

Closure by John R. Snell

JOHN R. SNELL,[1] M. ASCE.—The original paper under discussion is mainly the reporting of only the laboratory phases of an intensive laboratory and pilot study conducted under the writer's general supervision at Michigan State University. It should be pointed out that the discussions and recommendations included in the paper are drawn not only from the laboratory phases of the research reported in the paper, but from pilot scale and full scale work as well. These include pilot study work done at Michigan State University, and pilot and full scale work done in Kobe, Japan, where the writer acted as a consultant for two successive years. Papers reporting in detail the technical results of these pilot and full scale studies are presently under preparation. It should be made clear that the writer has taken some liberties in his recommendations beyond what might normally be drawn from laboratory research alone.

Reference is also made to two of the author's papers, which should answer most of the comments of Mr. Rogus in his discussion. These references are as follows: "Composting Your Organic Wastes at a Profit", which appears in the November issue of Public Works, and "Municipal Composting of Refuse", presented on October 28, 1957, before the Canadian Institute of Sewage and Sanitation in Toronto, Ontario.

In the latter paper, the writer's main thesis is that the next logical step in the development of composting of municipal refuse and other organic wastes is to construct a scientifically designed full scale prototype plant somewhere in the United States or Canada. This proposed 100 ton per day plant to compost mixed refuse is recommended with the thought of thoroughly trying three compost processes, which in the writer's opinion are the most promising, economically and scientifically. This paper also describes other methods of less promise which have been given some publicity, and in certain instances, have already demonstration plants in various parts of the country. It is suggested that the 100 ton per day plant be equipped with a receiving hopper, a picking belt and a magnetic separator which will remove salvageable metal, cans and bottles during such periods as the salvage market prices warrant. During other periods, it is suggested that materials removed before grinding may be limited to large difficult-to-grind materials, such as tires, tail-pipes, refrigerators and unchipped tree trimmings, etc. A reasonable percentage of coal ash would be acceptable as non-harmful to the composting process.

Grinding can be accomplished in a dependable and economical manner. Proof of the practicality of this contention is borne out in the 15 months'

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a. Proc. Paper 1178, February, 1957, by John R. Snell.

1. Partner, Michigan Associates, Lansing, Mich.

operation of the 80 to 100 ton per day operation at McKeesport, Pennsylvania. Here, two horizontal swing hammer type Gruendler grinders, in series, gave good service without delays from breakdowns. Operating experience indicated that hammers were built up on the average of once a week with hascolite welding rod and that the hammers themselves were reported to last over six months without replacement. In this operation, no attempt was made to remove either cans or bottles from the mixed refuse before grinding, thus giving more than normally expected wear and tear.

It is recommended that three composting methods be thoroughly tested at the proposed plant, each method handling roughly one-third of the daily input. The three methods recommended are as follows:

1. High-rate mechanical digester—the latest T. A. Crane Digester is recommended as the best, plus the possibility of adding a Dano Digester if added funds are available.
2. Modified windrow employing forced-air and an American Dross Disposal automatic turning and shreading machine.
3. Bin digester without turning, but employing forced air.

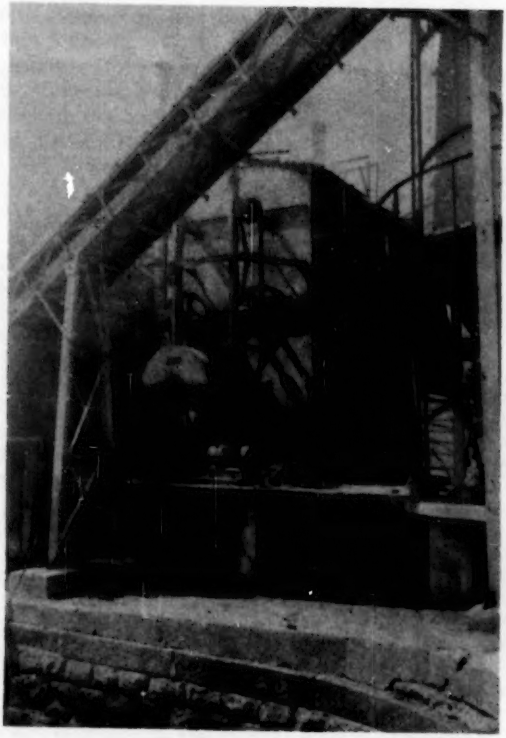
Excellent results have been reported from the T. A. Crane type digester constructed in Kobe, Japan. (See Fig. 1). A summary of these results have been given in the Toronto Paper. They indicate 70% of the expected stabilization taking place in 48 hours in the digester and 30% following in seven days of slow aeration in a second stage curing bin. The modified windrow process employing an American Dross Disposal automatic turning machine is presently being tried at the Omaha Stockyards with reported success. (See Fig. 2). Preliminary engineering estimates made by the writer indicate that this process is capable of treating stockyard wastes at the cost of $1.00 per wet ton and producing a compost end product at the cost of approximately $ 2.50 per dry ton. (10% moisture) The cost figures from the Kobe operation indicate $2.22 per ton of compost.

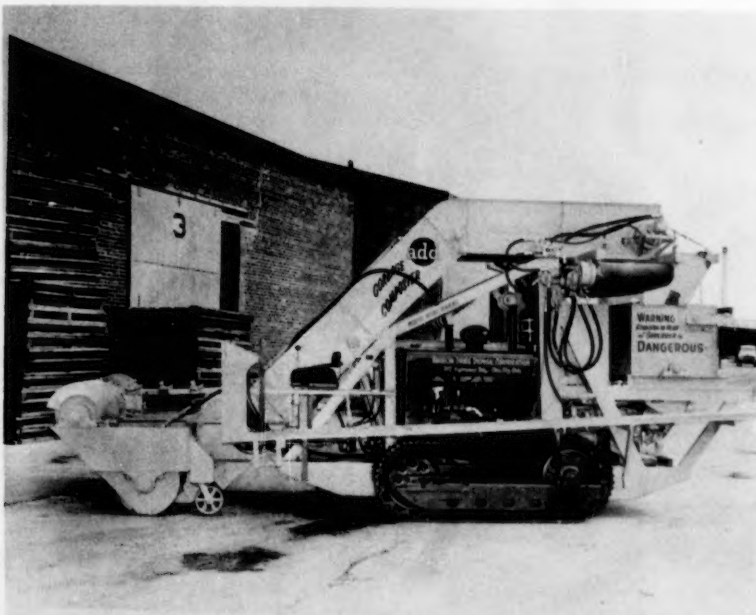
Bin composting with forced air is indicated as being at least as economical and having no moving parts. This process would take somewhat longer, perhaps as much as 15 to 20 days. The Kobe, Japan plant is designed so that the curing bins can be used either as a secondary digestion unit or as a primary unit, but as yet, no results are available for their use as a primary unit. Pilot scale experiments on 55 gallon drums gave very promising results, however.

The above information is presented with the idea of further demonstrating the practicality and the economics of composting and that, in fact, the next logical step is a full scale prototype plant.

Although Mr. Rogus' suggestion that a plant of this type is financed by the Federal Government, is not without merit, it is highly unlikely that it will come about. Equally unlikely is the possibility of such a plant being built from funds contributed by a foundation or a philanthropic individual. The paper presented in Toronto suggests six possible methods of financing. The three most likely of these are as follows:

1. By a single municipality, which may decide it would like to try composting. A good example of this is the city of Kobe, Japan. As a result of the construction of this plant, 38 other municipalities in Japan are anticipating construction of similar plants. The Federal Government of Japan is subsidizing these in the amount of 25%.
2. A second method of financing would be by joint venture of one or more

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municipalities and a privately formed company interested in producing and selling compost. A workable suggested formula would be for the municipality or municipalities to share 2/3, and the private compost company to share 1/3 of the capital cost. The city would then deliver all the refuse free to the plant and the private compost company would operate it for 5 years, or until its capital had been regained with an agreed-upon profit. All salvage and compost would be disposed of by the private company. The author knows of a nucleus of two private groups with venture capital who could be interested in some fair variation of this formula.

3. Another feasible financial plan would be to form a cooperative venture of 5 to 10 interested municipalities. A starting point here has already been made with the author sending out 15 letters at random to some of our larger cities. Four appear quite interested, two interested, two have not been heard from, three have the matter under consideration and five are not interested. A next step might be to broaden the base further and call a meeting of those interested in such a cooperative venture. The leadership of a municipality in this effort would be most welcome.

When such a plant is constructed and operated, it is urged that as much be learned from it as possible. In addition to the normal operating crew, there should be at least two chemists and one bacteriologist employed to follow the operation, and thus, point the way to improvements. Furthermore, detailed cost data should be kept on each method and translated into maintenance and operating costs for a plant of each type along. Many more chemical and bacteriological tests than those required for routine operation should be made and analyzed. It is believed that a National Institute of Health or Foundation grant could be obtained to defray the extra costs for research and economic studies of a prototype plant of this kind.

In closing, it should be stated that the cost of satisfactory present day refuse disposal methods vary from \$1.00 to \$6.00 per wet ton. Today a city employing a scientifically designed and operated composting process without considering the salvage or sale of the compost can at least match these costs and can in many cases appreciably lower them. If the sale of compost and the average salvage sale conditions are considered, then the treatment of organic municipal wastes by composting offers most cities over 100,000 population an actual and sometimes substantial source of revenue. Furthermore, it is firmly believed that conservation of these wastes should become a part of our way of life, or eventually our nations will suffer.

[illegible]

[illegible]

[illegible]

[illegible]

SANITARY ENGINEERING EDUCATION: ICA ASSISTANCE IN PERU[a]

Closure by Marvin L. Granstrom

MARVIN L. GRANSTROM.[1]—The writer wishes to thank Professor Babbitt for his interest and remarks. It is apparent from his comments that the teaching activities in sanitary engineering in Brazil are improving but that there are still important problems to be solved. This is also true in Peru.

It is the writer's pleasure to report that since the original paper was presented there has been considerable progress in the cooperative program between the University of North Carolina (UNC) and the National University of Engineering in Peru (UNI). UNC has supplied ten additional man months of service in Lima and each effort is more fruitful as developments are made. There is an increasing enthusiasm among the administration, faculty and students for the program. When it is considered that most of the faculty are visiting lecturers who contribute their time and energy for a very small remuneration, the willingness of each one to take on more responsibilities and to devote more time to the program is most encouraging. The subsequent discussion will mention briefly some of the late developments.

The physical facilities have been greatly improved with the completion of the hydraulics laboratory which is now being used by only the students in the Faculty of Sanitary Engineering. Next year the laboratory will be used by other students as well. With generous gifts from various companies and the Lima Water Department it was possible to construct a model rapid sand filter water treatment plant in the laboratory. Both treatment processes and hydraulics can be studied herein.

The personnel situation is still somewhat fluid. Not one of the three laboratory instructors trained at UNC is working at UNI. Upon return, one did not take employment at UNI, another (a young lady) was married and left Lima, and the third was killed in an accident on his way to Peru from the United States. One new employee has been found and others of the faculty are doing the laboratory teaching as well as giving the lectures. The quality of teaching is improving rapidly. Several new faculty members have been appointed and the over-all enthusiasm is marked. The Faculty is now making a self evaluation of the curriculum. This will result in a more completely integrated program. The spirit of the students is excellent and the enrollment has increased two- to three-fold since the inception of the program.

A program has been begun to utilize the laboratories for services as well as for teaching. The function will be to provide control and consultative services to governmental and private agencies concerned with water supply,

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a. Proc. Paper 1224, April, 1957, by Marvin L. Granstrom.

1. Associate Professor of Sanitary Engineering, School of Public Health, University of North Carolina, Chapel Hill.

water treatment and sewage treatment. In the past there was no such service laboratory and some water plant designs were made without due consideration of the quality of the raw water. The most important service contribution to date was the study of the sewage, sewerage system and stream pollution at the city of Arequipa, Peru. This was a cooperative study with the Ministries of Public Works and Public Health and with Servicio Cooperativo Inter Americano de Salud Publica in which UNI provided the personnel, equipment and supplies for the analytical work.

There still remains some need for assistance, particularly in further development of the service laboratory and in curriculum planning and course revision. UNI has requested and received an extension of the original contract from the International Cooperation Administration. The University of North Carolina has been requested to continue its activities on an abbreviated basis for at least an additional year. Study is now being made by UNC of this proposed extension.

FLOW OF CONCENTRATED RAW SEWAGE SLUDGES IN PIPES[a]

Discussion by Tsung-Lien Chou

TSUNG-LIEN CHOU,[1] M. ASCE.—The author is congratulated for his valuable contribution towards the solution of the urgent problem of determining the head loss in sewage sludge flow, in which rule of thumb still prevails.

The writer agrees with the author's adoption of solids concentration K in per cent by weight as the chief parameter for sludge classification for each variety, as its use is justified by the regular curves on Fig. C and D in his paper. It is to be regretted that the fundamental properties of the sludges, such as the specific weight ρ (pounds per cubic foot), the coefficient of rigidity η (pounds per foot per second), and the yield value S_y (pounds per square foot) are not known and also that more observations were not made, especially at higher velocities, to throw more light on some pertinent points.

The author summarizes his chief findings in Table A, but there is no indication of which kind of flow (Laminar or turbulent) the main experiments cover. It seems worthwhile to plot $S_p = 15.5D \frac{H}{L}$ (shearing stress in the flowing material at the pipe wall, pounds per square foot) against $\frac{v}{4D}$ as shown on Fig. E. The calculation is shown on Table C with the value of hydraulic gradient $s = \frac{H}{L}$ taken from author's curves on Fig. C and D. But it is necessary to raise the value from Fig. D. in order to match those Fig. C, such as for $\frac{v}{4D} = 1.15$ and $\frac{v}{4D} = 1.14$.

On Fig. E, the slope of the straight portion of each curve represents η and its intercept on the vertical axis gives $\frac{4}{3} S_y$. Though there are not enough points to trace out the whole flow picture of each solids concentration, especially the location of the critical velocity, they do define the straight parts, showing the variation of η and S_y with the solids concentration K. It should be noted that, in all cases except K = 10, the points of $\frac{v}{4D} = 3.84$ fall out of the straight lines. This may mean that, except K = 10, the velocity v = 5.11 fps is in turbulent region, while the rest are in laminar.

Next, we may turn to the important point of practical interest, that is, author's values of Hazen-Williams' C in Table A. For check, C's have been computed by the same formula and shown on Table D.

The calculated values of C on Table D are plotted on Fig. F against the

a. Proc. Paper 1274, June, 1957, by Sterling G. Brisbin.

1. Str. Engr., Edwards, Kelcey & Beck, Cons. Engrs., Newark, N. J.

Table C. $S_p = 15.5D \frac{H}{L}$ versus $\frac{V}{4D}$

D	$s = \frac{H}{L}$	$S_p = 15.5Ds$	$\frac{V}{4D}$	D	$s = \frac{H}{L}$	$S_p - 15.5Ds$	$\frac{V}{4D}$
	K = 10				K = 4		
4"	.378	1.95	3.84	4"	.118	.610	3.84
4"	.198	1.03	1.15	4"	.026	.134	1.15
6"	.133	1.03	1.14	6"	.0174	.134	1.14
6"	.094	.73	.34	6"	.0170	.130	.34
	K = 8.5				K = 2		
4"	.306	1.58	3.84	4"	.075	.387	3.84
4"	.137	.71	1.15	4"	.008	.041	1.15
6"	.917	.71	1.14	6'	.005	.041	1.14
6"	.069	.54	.34	6"	.0047	.038	.34
	K = 6						
4"	.186	.96	3.84				
4"	.060	.31	1.15				
6"	.041	.31	1.14				
6"	.037	.29	.34				

Table D. Hazen-Williams' C.

Solids Concentration	4 - inch Pipe (1) v = 5.11 fps					(2) v = 1.53 fps				
K	s scaled	C calc.	C' in % Of C at K - 0	Author's C'	Author's average C'	s scaled	C calc.	C' in % Of C at K - 0	Author's C'	Author's average C'
0	.050	93.53	100	100	100	.004	109.5	100	100	100
2	.075	75.1	80.5	85	81	.008	75.3	68.8	80	81
4	.118	58.9	62.8	60	61	.026	40.0	36.4	55	61
6	.186	47.1	50.5	50	45	.060	25.4	23.1	35	45
8.5	.306	35.2	37.6	37	32	.137	16.3	14.8	28	32
10	.378	31.4	33.6	32	25	.198	13.3	12.1	20	25
	6 - inch Pipe (3) v = 2.27 fps					(4) v = 0.68 fps				
0	.0065	96.8	100	100	100	.0025	48.6	100	100	100
2	.0115	71.2	73.5	80	81	.0035	40.5	83.4	80	81
4	.0235	48.4	50.0	60	61	.0055	31.8	65.5	70	61
6	.0415	35.6	35.7	40	45	.012	20.8	42.8	55	45
8.5	.0755	25.8	26.6	30	32	.029	12.9	26.6	32	32
10	.104	21.7	22.4	25	25	.048	9.6	19.8	25	25

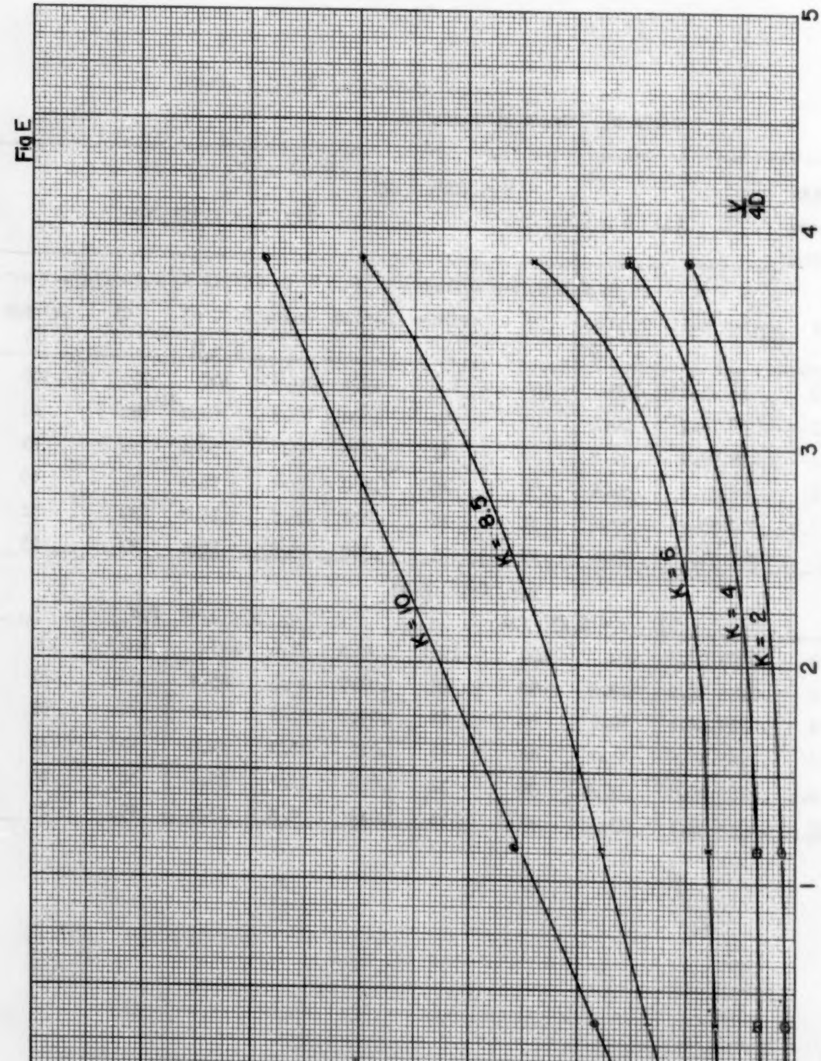
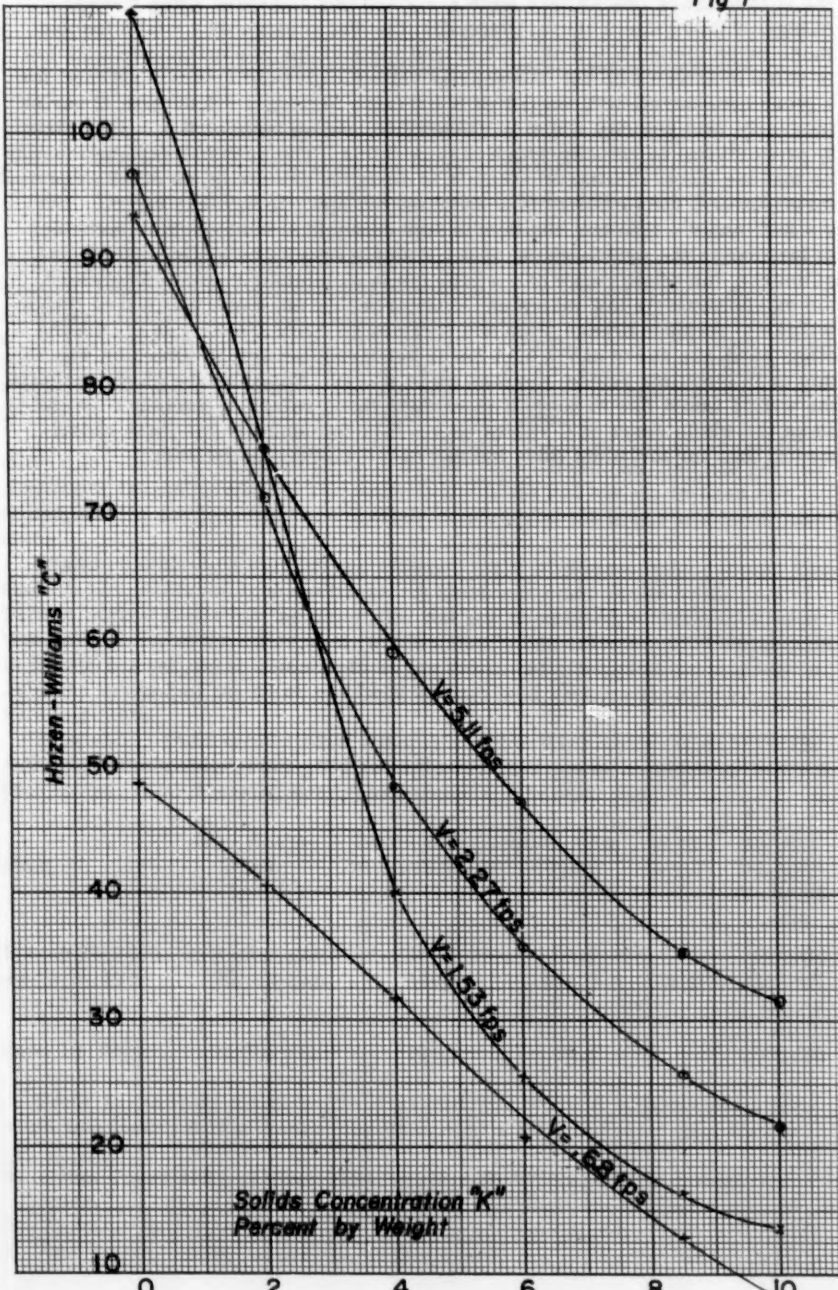


Fig E
Sp in lbs per Sq Ft
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
.0
0
1
2
3
4
5
V/4D
K = 10
K = 8.5
K = 6
K = 4
K = 2

Fig F


Hazen - Williams "C"
100
90
80
70
60
50
40
30
20
10
0
2
4
6
8
10
V=5.11 fps
V=2.27 fps
V=1.53 fps
V=.68 fps
Solids Concentration "K"
Percent by Weight

solids concentration K. The noteworthy point is that, except for v = 0.68 fps, the curves cross one another near K = 2 and this indicates some radical change of flow pattern there. Secondly, the whole range of v = 0.68 fps and those parts beyond K = 2 of v = 2.27 and v = 1.53 fps are extraordinarily low in value of C which do not necessarily reflect high head losses. Thirdly, for a given concentration K, on left of K = 2 (also barring v = 0.68 fps), C varies inversely with velocity which is reasonable, and on right of K = 2, C is directly proportional to velocity which is impossible. The possible explanation may be that the Hazen-Williams' formula is designed primarily, as other empirical formulas are, for turbulent flow and does not apply to laminar region. For v = 2.27 and v = 1.53 fps, the flow is apparently in transition from turbulent to laminar in the neighborhood of K = 2 as the concentration increases, and, of course, the whole range of v = 0.68 fps is in laminar region. Therefore, the extraordinarily low values of C indicates that the empirical law of Hazen-Williams' formula breaks down and there is no more meaning in C. On the other hand, the curve of v = 5.11 fps is quite regular and as shown on Fig. E, this is in turbulent region, perhaps up to K = 10. Based on the above analysis, the writer would like to suggest to exclude those values of laminar flow and to adopt the whole range of C values on v = 5.11 fps alone as the main experimental data for turbulent flow, instead of the average of the four.

TRICKLING FILTERS SUCCESSFULLY TREAT MILK WASTES[a]

Discussion by Leon E. Chase

LEON E. CHASE,[1] A.M. ASCE.—The writer recognizes the Plant A of the authors' article as an item of past experience. The subject plant is quite accurately described and has done a remarkable job of milk waste reduction since 1954—but as the authors state, judicious operation of such a plant means everything in good results—and the reverse is equally true. This discussion will be concerned with some of the procedures adopted to improve Plant A's operation, and to give some corroborative test results.

The filter was really designed as a standard rate filter; the stone bed is eight feet deep.[2] The plant was built in 1944, or thereabouts, and has been in continuous operation since. The stone in the filter bed has never been renewed, but the surface has been cleaned at intervals; the stone is a hard limestone.

Winter operation of Plant A has afforded many problems, with reduced flow and low temperatures at these times. A start was made in the latter part of 1956 to build a roof over the filter, but was not completed; a brick enclosure was built on top of the filter wall (which actually has afforded much protection in itself), but the cover remains to be installed. At infrequent times prior to 1956 the surface of the filter has been 90%covered with ice during severe winter months.

Independent tests conducted at Plant A confirm the results obtained by the authors, namely that a very good reduction in BOD can be obtained by Plant A processing. The following are typical results of 24 hour runs:

Date	Est. Waste Flow	BOD—ppm raw influent	BOD—ppm effluent	Recir. Ratio	Factory Intake—lb. whole milk
March 20-1956	24,940 gal.	1090	63.4		207,000
April 17-1956	23,012 gal.	1900	161.0	5.25	241,491 30,000 skim
June 12-1956	32,033 gal.	1430	17.4		317,600

Prior to the tests conducted by the authors at Plant A, experimental aeration was installed in the receiving tank, only a 100 cu. ft. per min. blower

a. Proc. Paper 1336, August, 1957, by Paul E. Morgan and E. Robert Baumann.
1. Engineer with Alvord, Burdick, & Howson, Chicago, Ill.
2. The design was by the late W. G. Kirchoffer.

was used, discharging through pipe orifices; the recieving tank was provided with temporary plank baffles, and a wood skimming trough was installed in one section. The slight amount of air proved most helpful in effecting removals of fatty solids, but inasmuch as the skimming had to be done by hand, the operation never became popular, but it was obvious that fat balls could be more easily removed from the surface of the receiving tank than fatty scum from the surface of the filter stone. Of course, with improved housekeeping in the factory, the fat content in the raw waste flow could most economically be reduced right in the factory, and this method was recommended. Further, with baffles in the receiving tank, and with the air turned off for short periods, an appreciable settlement of sludge was obtained in the initial section of the receiving tank; unfortunately, no effective means was then at the disposal of operating personnel for removing the sludge readily, but this settling was relieving the load on the final tank. Recirculation of the filter effluent was practiced somewhat as described by the authors. The aeration operation was interrupted when the blower had to be returned to its owner, but it was concluded that supplemental aeration in the receiving tank would be a distinct aid in the reduction process.

The most significant improvement in operation of Plant A occurred when factory management was convinced in late '55 summer that the digester was overloaded and that the obvious correction was to discontinue returning supernatant from the digester to the receiving tank, and in lieu of further digestion, to discharge the sludge on agricultural lands by truck haul; the factory acquired a special truck, fitted it with a tank and provided a plunger pump auxiliary, and started an operation that has continued to this date—in fact, settled sludge is at times pumped direct from the final tank, to the truck tank for disposal on lands and with no report of nuisance or health hazard creation.

PROCEEDINGS PAPERS

The technical papers published in the past year are identified by number below. Technical-division sponsorship is indicated by an abbreviation at the end of each Paper Number, the symbols referring to: Air Transport (AT), City Planning (CP), Construction (CO), Engineering Mechanics (EM), Highway (HW), Hydraulics (HY), Irrigation and Drainage (IR), Pipeline (PL), Power (PO), Sanitary Engineering (SA), Soil Mechanics and Foundations (SM), Structural (ST), Surveying and Mapping (SU), and Waterways and Harbors (WW), divisions. Papers sponsored by the Board of Direction are identified by the symbols (BD). For titles and order coupons, refer to the appropriate issue of "Civil Engineering." Beginning with Volume 82 (January 1956) papers were published in Journals of the various Technical Divisions. To locate papers in the Journals, the symbols after the paper numbers are followed by a numeral designating the issue of a particular Journal in which the paper appeared. For example, Paper 1449 is identified as 1449 (HY 6) which indicates that the paper is contained in the sixth issue of the Journal of the Hydraulics Division during 1957.

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FEBRUARY: 1162(HY1), 1163(HY1), 1164(HY1), 1165(HY1), 1166(HY1), 1167(HY1), 1168(SA1), 1169(SA1), 1170(SA1), 1171(SA1), 1172(SA1), 1173(SA1), 1174(SA1), 1175(SA1), 1176(SA1), 1177(HY1)[c], 1178(SA1), 1179(SA1), 1180(SA1), 1181(SA1), 1182(PO1), 1183(PO1), 1184(PO1), 1185(PO1)[c].

MARCH: 1186(ST2), 1187(ST2), 1188(ST2), 1189(ST2), 1190(ST2), 1191(ST2), 1192(ST2)[c], 1193 (PL1), 1194(PL1), 1195(PL1).

APRIL: 1196(EM2), 1197(HY2), 1198(HY2), 1199(HY2), 1200(HY2), 1201(HY2), 1202(HY2), 1203 (SA2), 1204(SM2), 1205(SM2), 1206(SM2), 1207(SM2), 1208(WW1), 1209(WW1), 1210(WW1), 1211(WW1), 1212(EM2), 1213(EM2), 1214(EM2), 1215(PO2), 1216(PO2), 1217(PO2), 1218 (SA2), 1219(SA2), 1220(SA2), 1221(SA2), 1222(SA2), 1223(SA2), 1224(SA2), 1225(PO)[c], 1226 (WW1)[c], 1227(SA2)[c], 1228(SM2)[c], 1229(EM2)[c], 1230(HY2)[c].

MAY: 1231(ST3), 1232(ST3), 1233(ST3), 1234(ST3), 1235(IR1), 1236(IR1), 1237(WW2), 1238 (WW2), 1239(WW2), 1240(WW2), 1241(WW2), 1242(WW2), 1243(WW2), 1244(HW2), 1245(HW2), 1246(HW2), 1247(HW2), 1248(WW2), 1249(HW2), 1250(HW2), 1251(WW2), 1252(WW2), 1253 (IR1), 1254(ST3), 1255(ST3), 1256(HW2), 1257(IR1)[c], 1258(HW2)[c], 1259(ST3)[c].

JUNE: 1260(HY3), 1261(HY3), 1262(HY3), 1263(HY3), 1264(HY3), 1265(HY3), 1266(HY3), 1267 (PO3), 1268(PO3), 1269(SA3), 1270(SA3), 1271(SA3), 1272(SA3), 1273(SA3), 1274(SA3), 1275 (SA3), 1276(SA3), 1277(HY3), 1278(HY3), 1279(PL2), 1280(PL2), 1281(PL2), 1282(SA3), 1283 (HY3)[c], 1284(PO3), 1285(PO3), 1286(PO3), 1287(PO3)[c], 1288(SA3)[c].

JULY: 1289(SM3), 1290(EM3), 1291(EM3), 1292(EM3), 1293(EM3), 1294(HW3), 1295(HW3), 1296 (HW3), 1297(HW3), 1298(HW3), 1299(SM3), 1300(SM3), 1301(SM3), 1302(ST4), 1303(ST4), 1304 (ST4), 1305(SU1), 1306(SU1), 1307(SU1), 1308(ST4), 1309(SM3), 1310(SU1)[c], 1311(EM3)[c], 1312 (ST4), 1313(ST4), 1314(ST4), 1315(ST4), 1316(ST4), 1317(ST4), 1318(ST4), 1319(SM3)[c], 1320 (ST4), 1321(ST4), 1322(EM3), 1323(AT1), 1324(AT1), 1325(AT1), 1326(AT1), 1327(AT1), 1328 (AT1)[c], 1329(ST4)[c].

AUGUST: 1330(HY4), 1331(HY4), 1332(HY4), 1333(SA4), 1334(SA4), 1335(SA4), 1336(SA4), 1337 (SA4), 1338(SA4), 1339(CO1), 1340(CO1), 1341(CO1), 1342(CO1), 1343(CO1), 1344(PO4), 1345 (HY4), 1346(PO4)[c], 1347(BD1), 1348(HY4)[c], 1349(SA4)[c], 1350(PO4), 1351(PO4).

SEPTEMBER: 1352(IR2), 1353(ST5), 1354(ST5), 1355(ST5), 1356(ST5), 1357(ST5), 1358(ST5), 1359(IR2), 1360(IR2), 1361(ST5), 1362(IR2), 1363(IR2), 1364(IR2), 1365(WW3), 1366(WW3), 1367(WW3), 1368(WW3), 1369(WW3), 1370(WW3), 1371(HW4), 1372(HW4), 1373(HW4), 1374 (HW4), 1375(PL3), 1376(PL3), 1377(IR2)[c], 1378(HW4)[c], 1379(IR2), 1380(HW4), 1381(WW3)[c], 1382(ST5)[c], 1383(PL3)[c], 1384(IR2), 1385(HW4), 1386(HW4).

OCTOBER: 1387(CP2), 1388(CP2), 1389(EM4), 1390(EM4), 1391(HY5), 1392(HY5), 1393(HY5), 1394(HY5), 1395(HY5), 1396(PO5), 1397(PO5), 1398(PO5), 1399(EM4), 1400(SA5), 1401(HY5), 1402(HY5), 1403(HY5), 1404(HY5), 1405(HY5), 1406(HY5), 1407(SA5), 1408(SA5), 1409(SA5), 1410(SA5), 1411(SA5), 1412(EM4), 1413(EM4), 1414(PO5), 1415(EM4)[c], 1416(PO5)[c], 1417 (HY5)[c], 1418(EM4), 1419(PO5), 1420(PO5), 1421(PO5), 1422(SA5)[c], 1423(SA5), 1424(EM4), 1425(CP2).

NOVEMBER: 1426(SM4), 1427(SM4), 1428(SM4), 1429(SM4), 1430(SM4)[c], 1431(ST6), 1432(ST6), 1433(ST6), 1434(ST6), 1435(ST6), 1436(ST6), 1437(ST6), 1438(SM4), 1439(SM4), 1440(ST6), 1441(ST6), 1442(ST6)[c], 1443(SU2), 1444(SU2), 1445(SU2), 1446(SU2), 1447(SU2), 1448(SU2)[c].

DECEMBER: 1449(HY6), 1450(HY6), 1451(HY6), 1452(HY6), 1453(HY6), 1454(HY6), 1455(HY6), 1456(HY6)[c], 1457(PO6), 1458(PO6), 1459(PO6), 1460(PO6)[c], 1461(SA6), 1462(SA6), 1463(SA6), 1464(SA6), 1465(SA6), 1466(SA6)[c], 1467(AT2), 1468(AT2), 1469(AT2), 1470(AT2), 1471(AT2), 1472(AT2), 1473(AT2), 1474(AT2), 1475(AT2), 1476(AT2), 1477(AT2), 1478(AT2), 1479(AT2), 1480(AT2), 1481(AT2), 1482(AT2), 1483(AT2), 1484(AT2), 1485(AT2)[c], 1486(BD2), 1487(BD2), 1488(PO6), 1489(PO6), 1490(BD2), 1491(BD2), 1492(HY6), 1493(BD2).

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FEBRUARY: 1528(HY1), 1529(PO1), 1530(HY1), 1531(HY1), 1532(HY1), 1533(SA1), 1534(SA1), 1535(SM1), 1536(SM1), 1537(SM1), 1538(PO1)[c], 1539(SA1), 1540(SA1), 1541(SA1), 1542(SA1), 1543(SA1), 1544(SM1), 1545(SM1), 1546(SM1), 1547(SM1), 1548(SM1), 1549(SM1), 1550(SM1), 1551(SM1), 1552(SM1), 1553(PO1), 1554(PO1), 1555(PO1), 1556(PO1), 1557(SA1)[c], 1558(HY1)[c], 1559(SM1)[c].

c. Discussion of several papers, grouped by divisions.

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